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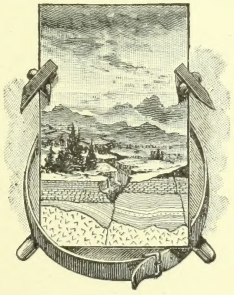

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WATER-SUPPLY PAPER 235

THE PURIFICATION

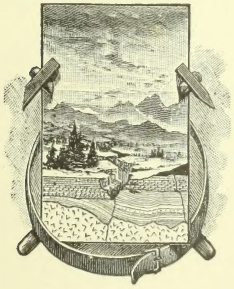
OF SOME

TEXTILE AND OTHER FACTORY WASTES

BY

HERMAN STABLER AND GILBERT H. PRATT

PREPARED IN COOPERATION WITH RHODE ISLAND
STATE BOARD OF HEALTH



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THE PURIFICATION OF SOME TEXTILE AND OTHER FACTORY WASTES.

By Herman Stabler and Gilbert H. Pratt.

INTRODUCTION.

Scope of paper.—This paper gives a brief outline of the processes of scouring wool, bleaching cotton yarn and cloth, dyeing cotton yarn, and manufacturing oleomargarine, glue, and fertilizer. The waste waters of these processes are considered in detail and means of purifying them are discussed at length, special prominence being given to the investigations of the authors. These investigations, which were begun in pursuance of an agreement for eleven months' cooperative work entered into August 1, 1906, between the United States Geological Survey and the Rhode Island state board of health, consisted of the determination of the effects of special industrial wastes on streams, their persistence, their relation to health, their damage to natural water resources, and the best methods of disposing of them, purifying them, or recovering valuable materials contained in them. The effect of the wastes on streams and the resulting damage to water resources has been detailed in another publication.[a]

The cooperative work was conducted under the joint supervision of M. O. Leighton, chief hydrographer of the United States Geological Survey, and Dr. Gardner T. Swarts, secretary of the Rhode Island state board of health, and the expense was shared equally by the organizations represented. The investigation of processes, the general field work, and a part of the laboratory experiments and analyses were conducted by Herman Stabler, assistant engineer, United States Geological Survey. The general laboratory work was conducted by Gilbert H. Pratt, chemist, Rhode Island state board of health. After the close of the cooperative work on June 30, 1907, the purification experiments were continued for several months by the state board of health, and the operation of an experimental purification plant that had been established and the installation and operation of other plants fell under Mr. Pratt's direction.

Acknowledgments.—Information as to processes, free access to factories, assistance in installing and maintaining experimental purification plants, and many other courtesies were extended by the manu-

[a] Stabler, Herman, Pollution of the Moshassuck * * * rivers: Spec. Rept. Rhode Island State Board of Health, 1908.

facturers affected by these investigations. The hearty cooperation thus received is acknowledged with thanks. A partial list of those who contributed to the research in this manner is as follows: Messrs. A. A. Sack, J. R. MacColl, F. A. Sayles, K. F. Wood, H. F. Schwarz, F. R. Mason, W. J. Burton, J. P. Farnsworth, F. R. Ames, H. G. McKerrow, S. Turner, and William Hartshorne.

Special acknowledgment is due Dr. Gardner T. Swarts for his personal interest in the investigations and for his active assistance in procuring the cooperation of manufacturing interests.

Free use has been made of the technical literature on the subjects treated. Where specific facts have been taken from such sources due credit is given, but the report also contains material gleaned from a perusal of the history of previous investigations, for which entire credit can not rightly be given to any one author.

WOOL SCOURING.

NECESSITY FOR TREATMENT.

Raw wool, as it comes from the sheep, is heavily impregnated with fatty matter, potassium salts, sand, and miscellaneous organic and inorganic materials. These impurities are derived partly from exudations from the skin of the animal and partly from outside sources, such as the soil over which the sheep moves. As it comes to the textile factory, therefore, wool may contain only from 20 to 80 per cent of fiber from which yarn may be produced. The separation of these impurities from the fiber is one of the most important processes of manufacture. The separation must be practically complete or all subsequent processes will suffer, for imperfectly scoured wool resists the action of mordants and takes a streaky color in dyeing, causes the fabric to become stiff and hard, and otherwise interferes with the production of high-class textiles. The scouring processes depend for their success on the use of softening and solvent agents which bring into solution some of the impurities and loosen others from the fiber so that they may readily be removed.

PROCESSES OF SCOURING.

SCOURING WITH SOAP, ALKALI, AND WATER.

The agents most commonly used for scouring wool are soap, alkali, and water. The operation is usually conducted in a series of three long, shallow iron tanks. These are nearly filled with water, to which soap and alkali are added in desired amounts. The wool is then fed continuously into the first tank, through which it is slowly carried by an ingenious system of moving rakes. Having reached the end of the first tank, the wool passes between rolls, which extract the moisture from it, and it falls into the second tank. Passage through the second and third tanks is accomplished in a similar manner.

The wool emerging from the third tank is practically free from impurities and is ready to be dried, oiled, and subjected to further manufacturing processes. As more and more wool passes through the scouring machine, the liquid in the tanks becomes very foul and the operation finally has to be discontinued. The scouring liquor is discharged from the first tank into the sewer, the liquor in the second tank is discharged into the first, the liquor in the third tank is discharged into the second, and the third tank is filled anew with clean water and other cleaning agents. In this way the waste liquors are highly concentrated, and water, soap, and alkali are used in an economical manner. Potassium soaps and potash are usually employed, because the sodium compounds, though less expensive, have an energetic corrosive action on the fiber, destroy its natural mellowness, and impart to it a yellow tinge. The potassium compounds, on the other hand, tend to whiten the wool and to give it a softened, diffusive character. Olive-oil soaps are most frequently used. The water is maintained during scouring at a temperature between 32° C. (90° F.) and 60° C. (140° F.). The higher temperatures are conducive to better cleansing, but they have a tendency to injure the wool.

For each thousand gallons of water, 40 to 45 pounds of soft soap and 5 to 10 pounds of potash are generally used in scouring from 1,000 to 2,000 pounds of raw wool to produce 600 to 900 pounds of clean wool fiber. These figures are, of course, only approximations; some scourers prefer a large amount of soap and no alkali, and others use very little soap and large quantities of alkali. At some mills the wool, after having been scoured, is rinsed in a running stream of fresh water.

STEEPING AND SCOURING.

As the impurities of wool include potash and wool fat, two valuable substances, special methods of cleansing have been adopted in order to facilitate the recovery of one or both of them from the scouring liquor. Steeping in tepid water as a preliminary to scouring is a procedure much followed in Europe, but little used in this country. The steeping, as usually practiced, is in reality an extractive process, for successive portions of water are passed through the wool, softening the impurities and removing the matters soluble in water. The steep water contains, in consequence, a large amount of potash.

After having been steeped, the wool is scoured as previously described. Although the steeping removes from the wool its natural content of the valuable scouring agent, potash, it renders scouring less costly, for it softens the impurities so that they may easily be removed from the fiber. This results in a saving of time and soap in scouring. The recovery of potash from steep water is another advantage derived from this procedure.

SCOURING WITH VOLATILE SOLVENTS.

Methods of scouring with volatile solvents have been devised in great numbers. The solvents proposed are petroleum-naphtha, carbon disulphide, and carbon tetrachloride. Because of the danger in the use of highly inflammable solvents and the expense entailed by loss of solvent, few of the patented processes have proved to be successful. Some of them, however, provide such perfect control of the solvent that its escape is negligible, and excessive cost and danger of fire have been obviated. Unfortunately these processes are jealously guarded for the exclusive use of the owners, so that their benefits are not open to textile interests generally.

In volatile solvent processes the raw wool is placed in suitable containers, the solvent is passed through it again and again until all the grease is extracted, and the solvent is removed from the wool and container by means of an inert gas. The solvent is recovered from the grease for subsequent use by distillation, and a valuable wool-fat product is left. After treatment with the solvent, the wool can be completely cleansed by warm water alone in the usual forms of scouring apparatus. It is claimed for such processes that the recovered wool fat is sufficiently valuable to pay for the extraction process. The gain in their use is measured partly by the saving in soap in the subsequent scouring process, but the greatest economy is said to be a saving in wool. It is claimed that the net yield of clean wool is far in excess of that obtained from the processes of scouring with soap.

WASTE WATERS FROM SCOURING WOOL.

CLASSIFICATION.

The waste waters from scouring wool vary in composition according to the methods of scouring and according to the differences of practice when the same general methods of scouring are employed. The wastes may be classified as follows: Steep water; sewage from scouring with soap and alkali after steeping; sewage from washing after treatment with volatile solvents; sewage from scouring with soap and alkali, and rinse water after scouring with soap and alkali.

STEEP WATER.

Treatment.—Steeping before scouring is practiced generally in France and Belgium and to a less extent in Germany, Russia, and England, but the method is almost unknown in the United States. As its object is the recovery of the potash in the wool, the steep water is used repeatedly until it becomes highly concentrated before the recovery processes are begun. Although there is considerable difference in practice at individual works, the average amount of liquor is approximately 1,000 gallons for 5,000 pounds of wool treated. The

steep water contains about 20 per cent of the weight of the wool treated, or about 40 per cent of the impurities in the wool. The constituents are mainly potassium compounds of organic and mineral acids, a small amount of similar sodium compounds, sand, dirt, and organic matter of various kinds. The residue obtained by evaporating the steep water amounts to about 120,000 parts per million (1,000 pounds per 1,000 gallons). About 40 per cent of this amount is organic or volatile matter and about 60 per cent is mineral matter. The alkalinity of the liquor corresponds to about 4,000 parts per million (33 pounds per 1,000 gallons) of potassium carbonate. In the recovery process the potassium compounds of organic acids are converted into potassium carbonate, thus largely increasing the yield of crude potash.

The process of treatment is simple. Usually the liquor, heated by waste furnace gases, is fed into an evaporator of the Porion type, passing first through an evaporating chamber and, after concentration has progressed to a suitable degree, passing into an incinerating chamber or common reverberatory furnace, from which crude potash is removed. The waste heat from the incinerating chamber accomplishes the evaporation. The liquor contains a considerable amount of inflammable matter which, burning in the incinerating chamber, assists the evaporation and reduces the amount of coal required for the process. Obviously the more concentrated the liquors are the more economically they can be utilized for the production of potassium salts.

Results.—Table 1 gives analyses of the potash obtained from the foregoing process:

TABLE 1.—*Analyses of potash recovered from wool-steep liquor.*

[Per cent of crude potash.]

	1.	2.	3.	4.	5.	6.	7.
Silica (SiO_2)	.....	6.2	6.0	1.4	0.1	.....	.....
Iron oxide (Fe_2O_3)	.....	.....	.....	Trace.	Trace.	.....	.....
Calcium (Ca)	.....	.....	.....	1.7	1.6	.....	.....
Magnesium (Mg)	.....	.....	.....	.6	.5	.....	.....
Sodium (Na)	2.0	1.4	1.3	2.0	Trace.	.....	2
Potassium (K)	48.8	48.5	48.4	49.0	52.7	53.6	48
Carbonate radicle (CO_3)	36.7	31.5	29.7	35.2	34.5	37.7	35
Sulphate radicle (SO_4)	1.7	1.2	1.3	3.8	3.8	1.5	3
Chlorine (Cl)	2.9	5.9	8.0	4.3	3.8	3.0	3
Phosphate radicle (PO_4)	.....	.....	.....	.9	.9	.....	.....
Insoluble matter	4.9	1.5	1.6	.....	.....	4.2	5
Water	.....	2.8	2.8	.....	.....	.....	3
Organic matter and undetermined, etc	3.0	1.0	.9	2.5	2.1	.....	1
	100.0	100.0	100.0	100.0	100.0	100.0	100

1. Analysis of potash from Doehren establishment. Analyst unknown. Wagner, Rudolf von, Manual of chemical technology; transl. by Sir William Crookes from the 13th German ed. of Dr. Ferdinand Fischer, 1904, p. 298.
2, 3. Analyses by Wérotte, Verviers, 1873. Wagner, Rudolf von. loc. cit.
4, 5. Analyses by Marcker and Schulz. Naylor, W., Trades waste; its treatment and utilization, 1902, p. 83.
6. Analysis by Maumené and Rogelet. Naylor, W., loc. cit.
7. Analysis of potash from a plant using the Richard-Lagerie apparatus. Analyst unknown. Naylor, W., op. cit., p. 85.

The content of potassium is nearly uniform in all the analyses, and it is approximately 50 per cent of the crude potash. In Table 1 the analyses have been calculated in ionic form for purposes of comparison. Table 2 contains a statement of the soluble salts as given by the analysts.

TABLE 2.—*Saline composition of potash recovered from wool-steep liquor.*

[Per cent of crude potash.]

	1.	2.	3.	4.	5.	Mean.
Potassium carbonate (K_2CO_3)	78.5	68.5	64.3	86.8	75	74.6
Potassium sulphate (K_2SO_4)	2.7	2.1	2.5	2.8	6	3.2
Potassium chloride (KCl)	5.7	12.5	16.9	6.2	6	9.5
Potassium silicate (K_2SiO_3)	.....	8.5	8.0	.....	.....	8.2
Sodium carbonate (Na_2CO_3)	4.6	3.2	3.1	.....	4	3.7

Potash in this crude form is worth from 3 to 4 cents a pound. It may be purified by extraction and crystallization, treatment that yields fairly pure carbonates, sulphates, and chlorides of potassium. A notable application of this procedure is found at the establishment of W. Graff at Lesum, where the pure salts were manufactured from the crude potash from six wool-scouring plants in 1878. According to Flekkel,[a] simple extraction and calcination of crude potash obtained from steep water gives a product which is 85 per cent pure potassium carbonate and is the purest commercial form known.

Costs and values.—A rough estimation of costs and values in this process may not be out of place. Naylor[b] quotes a statement placing the coal consumption for evaporating and incinerating at 1 pound for each pound of crude potash produced when a steep liquor of specific gravity 1.072 (10° Baumé, or 14.4° Twaddell) is treated. Fischer[c] estimates that 1 pound of Westphalian coal (analysis—carbon, 76.11; hydrogen, 4.52; sulphur, 1.19; oxygen and nitrogen, 10.06; ash, 8.12 per cent) is sufficient to evaporate and to calcine 12 pounds of steep liquor of specific gravity 1.069 (9.6° Baumé, or 13.8° Twaddell) and that the product is about 0.9 pound of crude potash. According to these estimates, evaporation and calcination would require about 745 pounds of coal per 1,000 gallons of steep liquor. If the preliminary concentration were conducted in a triple-effect vacuum avaporator, the amount of coal could probably be reduced to 425 pounds, but such a machine is economically adapted only to the concentration of large quantities of liquor. The following is a rough estimate of costs:

[a] Extraction of potash from suint of Russian wool: Bull. Soc. chim., 2d ser., vol. 34, 1880, pp. 332-333.
[b] Naylor, W., Trades waste; its treatment and utilization, 1902, p. 85.
[c] Fischer, F., Utilization of suint from wool: Dinglers polytech. Jour., vol. 229, 1879, pp. 446-449.

Yearly costs for treating 100 gallons an hour of steep liquor, ten hours a day, three hundred days a year.

Interest, depreciation, and repairs on plant, 15 per cent on investment of $5,000	$750
Labor	750
Coal, 132 tons, at $4 (this estimate allows additional coal for banked fires fourteen hours daily)	528
	2,028

Liberal allowance has been made for all costs. Such a plant would utilize the steep liquor from 5,000 pounds of wool daily, and plants for treating larger quantities of liquor and running twenty-four hours a day could be operated with much greater economy. On the assumption that the foregoing process would recover 84 per cent of the potassium in the wool as potassium carbonate worth 5 cents a pound, and that the remainder is valueless, the receipts would amount to 0.075 cent a pound of wool for each 1 per cent of potassium found by analysis, or 0.05 cent a pound of wool for each 1 per cent of recoverable potassium carbonate. A plant like the one just indicated would, therefore, produce an annual revenue of $1,125 for each 1 per cent of potassium, or $750 for each 1 per cent of potassium carbonate in the wool. In order to pay costs as estimated, this plant would necessarily have to operate on liquor from wool containing 1.8 per cent of potassium or 2.7 per cent of recoverable potassium carbonate. Each additional 0.044 per cent of potassium, or 0.067 per cent of recoverable potassium carbonate, would return a profit of 1 per cent on the investment of $5,000. With the average wool, containing over 4 per cent of recoverable potash, a substantial return on the investment is to be expected.

Production of ferrocyanide.—Another method which has been suggested for utilizing steep water is that of evaporating it to dryness and heating it in a closed retort for the production of potassium ferrocyanide, or yellow prussiate of potash. The residue obtained by evaporation to dryness is an intimate mixture of potassium salts and organic matter, and after the addition of iron filings and nitrogenous waste in proper proportions, it is one of the best mixtures for the production of ferrocyanide. This method was proposed by Havrez [a] in 1870, and it was successfully tried on an experimental scale at the Peltzer works in Verviers. Although it is improbable that the method will come into use at wool-scouring establishments, it indicates a market in the chemical industries for a potash residue which may easily be obtained at such works. It is stated that the value of the residue of steep water, when used in this way, is more than twice its ordinary commercial value.

[a] Havrez, P., Wagner's Jahresbuch, 1870, pp. 210 and 222; Dinglers polytech. Jour., vol. 195, p. 535.

SEWAGE FROM SCOURING AFTER STEEPING.

As 40 per cent of the impurities of the wool are removed by steeping, the sewage from scouring after steeping contains the remaining 60 per cent of the impurities. This waste differs from ordinary scouring liquor chiefly by reason of the absence of the potassium compounds that are in raw wool. It contains large amounts of organic matter, wool fat, soaps used in scouring, and other substances, and its practical purification can be best effected by the means adopted for ordinary scouring liquor (see pp. 14–17) except those in which the recovery of potash is an important element.

SEWAGE FROM WASHING AFTER TREATMENT WITH VOLATILE SOLVENTS.

Sewage from washing wool after treatment with volatile solvents is closely allied in character to the steep water already considered. It differs from steep water in that it contains a greater percentage of the wool impurities, other than potash, and for this reason it is less valuable for potash recovery. On the other hand, its greater content of organic impurities should give it a greater value than steep water in the production of potassium ferrocyanide. The solids of this liquor consist of about 40 per cent mineral and 60 per cent organic matter. The yearly cost for potash recovery from it would be from $500 to $800 greater than that given on page 11 for recovery from steep water for the same quantity of raw wool, and the quality of crude potash would be much inferior, averaging probably not more than 50 per cent pure potassium carbonate. As a larger quantity of inferior potash would be produced, the economy of the process would be considerably lessened by cost of marketing the product unless the potash were purified on the premises. Furthermore, the greater proportion of suspended matter in this liquor makes economic evaporation difficult.

It would seem that the dried residue after evaporation of such liquor would make an excellent fertilizer stock. Attempts to market it in this way, however, have been unsuccessful.

If mere purification without recovery of potash is desired, this liquor can be successfully treated by slow filtration through sand. From 65 to 85 per cent removal of total organic matter and entire removal of suspended matter was effected at a rate of 12,300 gallons per acre per day by this method at the Lawrence sewage experiment station.[a] Such purification would cost:

Annual cost of daily purification of 2,000 gallons of sewage from washing wool after treatment by volatile solvents.

Interest, repairs, and depreciation, 15 per cent on an investment of $1,500	$225
Labor, one-half of one man's time, at $1.50 a day	225
	450

[a] Thirty-sixth Ann. Rept. Massachusetts State Board Health, 1904, pp. 276–277.

Whether this treatment would be less expensive than potash recovery would depend chiefly on the quantity and the potash content of the wool scoured and on the amount of water used in scouring

SEWAGE FROM RINSING AFTER SCOURING.

If the wool is rinsed after scouring with soap and alkali the resulting waste water is usually very dilute and contains no materials of sufficient value to warrant their recovery. Purification by common sewage methods is usually satisfactory. Experiments at Lawrence, Mass.,[a] indicate that if rinse water, which may vary from 5 to 100 gallons for each pound of wool scoured, is mixed with sewage, it can be satisfactorily purified by filtration through sand at high rates. Rates exceeding 500,000 gallons per acre per day were maintained in some of these experiments.

SEWAGE FROM SCOURING WITH SOAP AND ALKALI.

The sewage which results from scouring wool with soap and alkali is the "wool-scouring liquor" commonly encountered in this country. It is an ill-smelling liquor of brownish color, heavily charged with impurities in solution and in suspension. It contains soap, wool fats, and potash in sufficient quantities to form a heavy emulsion, and on this account the liquor is very hard to filter in the laboratory. The analyses in Table 3 show the general composition of the scouring liquor and some of the variations in character likely to be encountered at different mills.

TABLE 3.—*Analyses of wool-scouring liquor.*

[Milligrams per liter, unless otherwise stated.]

	1.	2.	3.	4.	5.
Specific gravity	1.023	1.027	1.019	.....	.....
Turbidity	22,000	120,000	55,000	.....	.....
Scum .....per cent by volume	.....	8	Slight.	20	.....
Sediment .....do	15	8	20	14	.....
Total solids	45,090	116,400	68,060	70,800	41,700
Volatile	24,670	85,000	50,710	46,600	29,800
Fixed	20,420	31,400	17,350	24,200	11,900
Alkalinity	8,000	8,000	3,100	3,800	3,420
Fats	14,600	59,000	38,200	31,620	20,200
Oxygen consumed	5,680	11,500	5,700	5,200	.....
Nitrogen as free ammonia	300	300	164	180	.....
Organic nitrogen	663	1,550	795	941	.....

1. Liquor from woolen mill of Lymansville Company, Lymansville, R. I., November 13, 1906.
2. Average of three samples, Lorraine Manufacturing Company, Pawtucket, R. I., March 13, 1907.
3. Average for week ending March 29, 1907, Lorraine Manufacturing Company, Pawtucket, R. I.
4. Average for week ending May 23, 1907, Lorraine Manufacturing Company, Pawtucket, R. I.
Analyses 1 to 4 by G. H. Pratt and H. Stabler.
5. Crude suds from Field Head Mills, Bradford, England, May, 1900. Analysis by F. W. Richardson, Bradford public analyst.

[a] Thirty-second Ann. Rept. Massachusetts State Board Health, 1900, p. 415.

PURIFICATION OF WOOL-SCOURING LIQUOR.

SEWAGE-TREATMENT METHODS.

The methods of treating wool-scouring liquor in which purification is the sole object include the common processes of sewage purification, namely, sedimentation, precipitation, and filtration.

The Massachusetts state board of health has conducted for several years experiments on the purification of wool-washing wastes by sewage methods, and a summary [a] of five years' work by that body may be given as follows:

1. A considerable amount of suspended matter can be removed by sedimentation. The amount of organic matter deposited can not be materially increased by reasonable amounts of common precipitants alone or in combination. Ferric chloride and lime or lime alone will sometimes precipitate considerable quantities of organic and fatty matter.

2. Acids separate fats, but they give an acid liquor that is hard to treat.

3. Filtration through sand is inexpedient, because the liquor does not nitrify by itself and the filters quickly clog.

4. Scouring liquor mixed with sewage can be purified and nitrified in intermittent sand filters.

5. A higher rate of filtration and less clogging of filters result from holding the mixture of scouring liquor and sewage for bacterial action, including putrefaction, before filtration.

6. Mixtures of scouring liquor and sewage that can be purified in sand filters can not be purified in contact filters.

It is evident from this summary that a high degree of purification can not be obtained by sedimentation, chemical precipitation, or filtration under reasonable conditions of practice.

The results obtained by septic treatment of mixed sewage and wool-scouring liquor for 1900 were very good and are indicated in Table 4, adapted from the report [b] previously mentioned.

TABLE 4.—*Analyses of mixed sewage and wool-scouring liquor before and after purification.*

[Milligrams per liter.]

Source of sample.	Color.	Free ammonia.	Albuminoid ammonia.	Nitrogen as nitrates.	Nitrogen as nitrites.	Oxygen consumed.
Mixture of 11 parts sewage and 1 part scouring liquor	.....	36.50	14.30	.....	.....	164.0
Mixture filtered at rate of 47,600 gallons per acre per day, 6 days a week	215	.19	1.68	16.3	.000	28.3
Mixture passed through septic tank and filtered at rate of 46,100 gallons per acre per day, 6 days a week	173	.22	1.44	29.1	.023	22.5

[a] Loc. cit.

[b] Op. cit., p. 416.

The liquor treated by this method, however, is very different from the wool-scouring liquor represented by the analyses in Table 3. The scouring liquor used in all the Massachusetts experiments was rather dilute, and the successful filtration experiments were made on this dilute liquor still further reduced by eleven times its volume of sewage. It appears that even the best results obtained in these experiments show that the method can not be employed at many wool-scouring establishments. Treatment of wool-scouring liquor by usual sewage methods, therefore, can not be recommended, except in cases where a comparatively small percentage of purification is all that is desired.

The conclusion reached above is corroborated by the results of treatment by sedimentation at Lymansville, R. I. The wastes at the woolen mill of the Lymansville Company are dye water, 3,000 to 4,000 gallons; piece-scouring and rinsing water, 5,000 to 6,000 gallons; and wool-scouring liquor, 5,000 to 6,000 gallons. Piece-scouring suds and dye water, in intermittent flow during the day, are collected in two 9,500-gallon brick cisterns, which are used alternately. At noon and at the end of the day wool-scouring liquor to which has been added slaked lime to the amount of 50 pounds a day, or 1 pound to about 300 gallons of the combined liquors, is admitted. These cisterns serve primarily as receiving and mixing basins, but the mixed liquors are also freed in them from coarse and heavy suspended matters. The cisterns are cleaned once in three weeks, when about 9 cubic yards of sludge are removed. This sludge is dumped near by until excess of water has drained off, and is then carted away. It contains, as shown by analysis of a sample taken from the dump, total solids, 79.7 per cent (volatile solids, 4.5 per cent; fixed solids, 75.2 per cent); fats, 1.4 per cent; and nitrogen, 0.12 per cent. It is chiefly sand, wholly unsuitable for fertilizing purposes, and it probably can not be utilized in any way.

The combined liquors are pumped from the receiving cisterns into the first of a series of four reservoirs. The sizes of these reservoirs and the periods of storage afforded by them are shown in Table 5.

TABLE 5.—*Waste liquor reservoirs at Lymansville, R. I.*

Reservoir No.	Dimensions.	Capacity.	Storage period.
	Feet.	*Gallons.*	*Days.*
1	45 by 60 by 4	81,000	5.4
2	35 by 18 by 4	18,900	1.3
3	40 by 18 by 4	21,600	1.4
4	45 by 18 by 4	24,300	1.6
	.....	145,800	9.7

The system is practically one of sedimentation, though the effluent from reservoir No. 4 passes through a bank of coarse cinders. The first of the reservoirs is cleaned about once in six months, when 25 cubic yards of scum and an equal amount of sludge are removed. Only slight

accumulations are found in the other reservoirs. In a year, therefore, 160 cubic yards of material are removed from the wastes in the receiving cisterns, 100 cubic yards in reservoir No. 1, and about 10 cubic yards in the other reservoirs, making a total of 270 cubic yards of material removed from the wool-scouring wastes. The scum from reservoir No. 1 contains 24.1 per cent total solids (15.4 per cent volatile solids, 8.7 per cent fixed solids), 4.8 per cent fat, and 0.4 per cent nitrogen. The sludge contains 29.5 per cent total solids (14.1 per cent volatile solids, 15.4 per cent fixed solids), 4.2 per cent fat, and 0.5 per cent nitrogen. This material undoubtedly has some manurial value, but the great content of moisture (70 to 75 per cent) renders it practically valueless because of cost of transportation or of drying. Correcting for the moisture and assuming an average weight of 80 pounds per cubic foot for the 270 cubic yards of material, it appears that a total removal of 357,000 pounds per annum is accomplished. This is a maximum figure. The waste liquors contain about 1,000,000 pounds of solid matters. A purification of upward of 36 per cent is therefore effected. It should be noted, however, that by far the greater part (about 75 per cent) of this purification takes place in the receiving basins. In Table 6 analyses of the various waste liquors at Lymansville are presented, together with analyses of the combined liquors at different stages in the sedimentation system.

TABLE 6.—*Analyses of waste waters at Lymansville, R. I.*[a]

[Milligrams per liter, unless otherwise stated.]

Source of sample.	Turbidity.	Color.	Sediment.	Organic nitrogen.	Nitrogen as free ammonia.	Oxygen consumed.	Fats.
			Per cent.				
Dye water	400	Black	[b]	7	43	364	14
Piece-scouring suds	1,200	Slate	[c]	69	1	560	900
Wool-scouring liquor	22,000	Brown	15	663	300	5,680	14,600
Inflow reservoir No. 1	10,300	do	7.2	215	183	1,700	5,940
Effluent reservoir No. 1	9,700	do	3.0	194	169	1,690	5,430
Effluent reservoir No. 2	9,700	do	2.2	194	143	1,700	4,950
Effluent reservoir No. 3	8,000	do	2.1	188	145	1,680	4,380
Effluent reservoir No. 4	8,500	do	1.3	184	134	1,680	5,070
Final effluent	9,700	do	1.0	190	133	1,700	4,850

Source of sample.	Chlorine.	Alkalinity.	Total solids.		Solids in solution.	
			Total.	Loss on ignition.	Total.	Loss on ignition.
Dye water	5	114	790	690	790	690
Piece-scouring suds	100	1,990	4,610	2,140	3,960	1,510
Wool-scouring liquor	1,100	8,000	45,090	24,670	31,120	13,080
Inflow reservoir No. 1	400	3,560	19,600	12,500	11,080	4,670
Effluent reservoir No. 1	400	3,250	16,530	9,400	11,770	5,000
Effluent reservoir No. 2	400	3,750	16,010	9,140	11,610	5,050
Effluent reservoir No. 3	400	3,750	15,520	8,640	11,240	4,670
Effluent reservoir No. 4	400	3,750	15,730	8,760	11,590	4,920
Final effluent	400	3,750	15,900	8,960	11,360	4,680

[a] Analyses by G. H. Pratt and H. Stabler. [b] Considerable. [c] Heavy.

The mixing of the wool-scouring liquor with the other waste waters assists materially in the precipitation of solids; but the reduction in impurities, even under these favorable conditions, is comparatively small. It appears from the figures presented in Table 6 that the entire system of reservoirs, considered aside from the receiving basins, with nearly ten days' storage accomplishes a reduction of only 6 per cent in turbidity, 86 per cent in sediment, 19 per cent in total solids, 28 per cent in loss on ignition, 2 per cent in fixed solids, 12 per cent in organic nitrogen, 27 per cent in free ammonia, 18 per cent in fats, and practically nothing in oxygen consumed or solids after filtration. In the first reservoir alone there is a reduction of 6 per cent in turbidity, 58 per cent in sediment, 16 per cent in total solids, 25 per cent in loss on ignition, nothing in fixed solids, 10 per cent in organic nitrogen, 8 per cent in free ammonia, and 9 per cent in fats. There appears to be little gain in prolonging the period of sedimentation beyond five days. It is even probable that a carefully constructed sedimentation basin with a twenty-four to forty-eight-hour period would accomplish as much purification as the entire system of reservoirs in use at Lymansville, for it should be understood that these reservoirs are mere excavations in the earth and that no precautions were taken in their construction to produce an even flow throughout their cross sections. It is probable that the liquor moves through them in a comparatively narrow current and hence is subjected to a much shorter period of sedimentation than their capacities indicate.

PURIFICATION BY RECOVERY.

The methods of purification which involve the recovery of valuable products are more successful in reducing the impurities of wool-scouring liquors than the methods applied for the sake of purification only. The valuable substances which have been recovered on a practical scale are fats and potash, both of which are found in large amounts in the fleece and both of which are added in the scouring process. The most prominent of the methods that have been used successfully will be described.

Cracking process.—The earliest and at present the most usual method of recovery treatment for wool-scouring liquor is known as the "cracking process." In the routine of this process, the liquor is first allowed to settle for a short period to remove the greater portion of insoluble mineral matter. It is then drawn into wooden or lead-lined tanks and treated with sulphuric acid. Acid is added until a breaking up of the liquor or "cracking" is noticed. At this point the liquor has a decidedly acid reaction. The result of the addition of acid is that the fatty compounds are broken up with the formation

of free fats. The separation of the fats from the mother liquor is, however, somewhat difficult. Usually, after one or two days sedimentation, a considerable portion of the fatty matter collects on the surface and a nearly equal amount at the bottom of each tank, while the middle portion is comparatively clear and free from suspended matter. This middle portion is drawn off and run to waste, while the fatty matters at top and bottom are removed to sludge filters covered with sawdust, in order that surplus moisture may drain off.

The material usually placed on these filters amounts to about one-third of the total volume of the wool-scouring liquor. The sludge, after draining about four days on the filters, is collected in cloths and is made into thin cakes. These cakes are placed in presses heated by steam, which melts the fats so that the resulting oil can be removed by pressure. The mixed water and oil which flows from the presses is collected in cisterns and separated by sedimentation. The oil is subjected to purification by being boiled with a little acid, after which it is allowed to settle and cool in order that any remaining traces of water, acid, and other impurities may be run off. The oil, when cool, solidifies, and it is sold under the name of "de gras," or Yorkshire grease. It is worth from 1½ to 3 cents a pound. A large proportion of the mineral and organic impurities of the wool-scouring liquor remains in the presses in the form of hard-pressed cakes, which are removed and generally thrown away as a waste product. Some establishments have extracted these cakes with volatile solvents in order to obtain a greater yield of fats, but such procedure has not generally been financially successful because of loss of solvent. In Europe they have been used to some extent as a fertilizer base, but their value for this purpose is at least subject to doubt.

Detailed examinations were made at the de gras plant of the Lorraine Manufacturing Company, Pawtucket, R. I. At this establishment preliminary sedimentation of the liquor is omitted, and, in consequence, an usually large proportion of suspended mineral matter is carried through the entire process. Three sets of samples were collected. The scouring liquor of these sets is represented by analyses 2, 3, and 4 of Table 3. Analyses of the waste waters from the acid-treating tanks, of waste waters from the separating cistern which receives mixed water and oil from the presses, and of waste waters from the purification of the oil by boiling with acid, are listed in Table 7. Several samples of the press cake were found to contain fats amounting to 25.2 per cent, 26.3 per cent, 16.7 per cent, and 22.7 per cent of the weight of the dried cake.

TABLE 7.—*Analyses of waste waters from the de gras plant of the Lorraine Manufacturing Company at Pawtucket, R. I.*[a]

[Milligrams per liter, unless otherwise stated.]

	Treating-tank effluent.			Water from separating cistern.		Water from grease purification.
Date, 1907	Mar. 13.	Mar. 22–29.	May 17–23.	Mar. 29.	Mar. 14.	Mar. 14.
Turbidity	1,500	8,000	.....	4,000	4,500	160
Sediment	1.2 per cent.	Heavy.	3.5 per cent.	Considerable.	Considerable.	Considerable.
Oxygen consumed	1,800	2,160	2,800	1,600	1,320	1,025
Nitrogen as free ammonia	330	230	289	80	89	98
Organic nitrogen	200	258	346	402	238	150
Acidity as $CaCO_3$	1,600	2,200	3,000	500	400	34,000
Fats	1,360	4,420	7,000	2,352	2,275	600
Total solids	19,600	21,010	27,670	10,570	10,150	.....
Loss on ignition	6,900	9,960	13,310	7,970	6,200	.....
Fixed solids	12,700	11,050	14,360	2,600	3,950	.....
Shrinkage of wool scoured	High.	42 percent.	48 percent.	.....	.....	.....

[a] Analyses by G. H. Pratt and H. Stabler.

Table 8 gives in detail the manner in which the scouring liquor at the Lorraine mill is treated, together with estimates of relative volumes at different steps based on 1,000 gallons of scouring liquor. The probable composition of the various materials is also estimated.

TABLE 8.—*Disposal of wool-scouring liquor at the de gras plant of Lorraine mill, Pawtucket, R. I.*

Source.	Total amount of material.		Water.		Composition.			
					Total solids.	Volatile solids.	Fixed solids.	Fats.
	Galls.	*Pounds.*	*Galls.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
Scouring liquor	1,000	8,520	948	7,941	579	406	173	291
Acid used	5.2	77	1.5	13	.....	.....	.....	.....
Liquor from acid-treating tanks	620	5,290	619	5,164	126	60	66	30
Filter effluent	225	2,174	254	2,122	52	25	27	12
Material pressed	.....	1,093	80	668	425	321	104	249
Liquor from cisterns	167	1,405	167	1,391	14	10	4	3
Liquor from purification of grease	7	60	7	60	Trace.	.....	.....	Trace.
Grease recovered	.....	183	.....	Trace.	183	183	Trace.	183
Press cake	.....	255	3	27	228	128	101	63
Total liquid effluent	1,049	8,929	1,047	8,737	192	95	97	45

Comparison of the raw liquor and the total liquid effluent indicates a reduction of 66.7 per cent in total solids, 76.6 per cent in volatile solids, 46 per cent in fixed solids, and 84.5 per cent in fats. This is a much better purification than has been obtained by the usual sewage treatment methods.

Table 9 gives a comparison of the results obtained at the Lorraine mill and at several English establishments, as calculated from analyses of the raw liquor and of the effluent from the acid-treating tanks:

TABLE 9.—*Per cent of solids and grease removed from or added to wool-scouring liquor by cracking process.*

Factory.	Total solids.	Volatile solids.	Fixed solids.	Grease.
Greenwood & Hanson	−66	−78	− 43	−82
Broadbent	+39	+ 9	+125	−20
Schofield	− 3	−26	+ 80	−83
Millor	− 8	−13	+ 13	−50
Shaw	+10	−11	+125	−32
Average	− 6	−24	+ 60	−53
Lorraine, March 22–29	−69	−80	− 36	−88
Lorraine, May 17–23	61	71	41	−78

NOTE.—Plus signs indicate material added to the liquors; minus signs indicate material removed from the liquors.

The data for the English establishments are quoted from Naylor[a] as representing the "rule of thumb" treatment of the early days of the process. The comparison is favorable to the operations at the Lorraine mill.

Turner-Akeroyd process.—A modification of the cracking process has been patented in England by Turner and Akeroyd. The usual procedure is most successfully applied to a highly concentrated liquor. The Turner-Akeroyd modification, on the contrary, is applied most successfully to dilute liquors, and can, therefore, be used for the treatment of piece-scouring suds or other comparatively dilute soapy waste waters. The process is intended to effect a more complete separation of fats than can be accomplished in the ordinary method of treatment. The scouring liquor is collected in a precipitation tank, where it is diluted to such specific gravity that the fats which have separated on the addition of acid can all readily sink to the bottom, leaving a clear supernatant liquor. The liquor is agitated for several hours by blowing air through distributors in the bottom of the tank. Acid is then added, and if this alone will not produce the desired separation of fats, a small amount of fine earth is introduced in order to give weight to the precipitate and carry it to the bottom. The treatment of sludge follows the methods of the ordinary cracking process. The system includes filtration of the liquor from the acid-treating tank through gravel overlain with a few inches of ashes and topped with a sprinkling of sawdust. Grease gathers on the surface of the filter and is collected from time to time and pressed for the recovery of fats.

The following table shows the character of the liquors in a Turner-Akeroyd plant at Pittsfield, Mass.:

[a] Naylor, W., Trades waste; its treatment and utilization, 1902, p. 75 (quoted from Third Rept. Rivers Pollution Commissioners, vol. 1, p. 32.)

TABLE 10.—*Analyses of waste liquors from Turner-Akeroyd plant at Pontusac mill, Pittsfield, Mass.*[a]

[Milligrams per liter.]

	Scouring liquor.	Liquor from acid-treating tank.	Filter effluent.
Turbidity	4,500	370	50
Oxygen consumed	410	89	64
Nitrogen as free ammonia	2.6	5.5	5.6
Organic nitrogen	47.6	9.1	6.1
Alkalinity as $CaCO_3$	980	[b] 425	[b] 170
Sulphate radicle (SO_4)	Small amount.	1,970	1,660
Iron (Fe)	Trace.	5	2.5
Fats	2,140	175	38
Total solids	4,740	.....	2,460
Volatile solids	3,200	.....	100
Fixed solids	1,540	.....	2,360

[a] Analyses by G. H. Pratt and H. Stabler. [b] Acidity.

The analyses indicate more thorough purification than is obtained by the other methods of treatment that have been discussed. A sample of press cake from this plant contained 2.6 per cent moisture, 78.4 per cent volatile solids, 19.0 per cent fixed solids, 22.4 per cent fats, and 3.8 per cent nitrogen. Effluent liquors from the ordinary cracking or the Turner-Akeroyd process can be further purified by neutralization with lime and subsequent filtration. This procedure is followed in many European plants where a high degree of purification is essential.

Battage process.—The battage process of grease recovery is followed successfully in France. The scouring suds are conveyed into a narrow tank divided into numerous compartments and provided with agitators which beat up the liquor, raising froth which carries the fats to the surface. The greasy lather thus produced is removed by means of scrapers. Various modifications of this process provide for agitation by means of beaters, compressed air, superheated steam, and other agencies, the object of all being to produce a froth which can readily be removed by skimming. The grease removed in this way is then recovered by treatment with acid and by pressing, as in the cracking process. Several qualities of grease may be obtained. The lather produced in the first compartments is light colored, and it yields a grease of much better quality than that which is obtained from the lather skimmed from the last compartments of the apparatus.

Smith-Leach process.—Another process results in the recovery of fats by means directly opposed to those employed in the Turner-Akeroyd patent. The first procedure is concentration instead of dilution, and the scouring liquor is thus reduced to one-tenth or a less proportion of its original volume. It then has specific gravity of about 1.15 (20° Baumé, or 30° Twaddell). At this concentration the liquor has a sirupy consistency, and on sedimentation and cooling the grease collects at the top and is removed by skimming. In the Smith-Leach modification of this process the separation of the grease

from the concentrated liquor is accomplished by means of a centrifugal machine similar to the ordinary cream separator. The grease so obtained is nearly pure wool fat (60 to 70 per cent of the entire grease), which commands a price twice as great as that of the grease recovered by the cracking process.

Potash recovery alone has not been applied to ordinary wool-scouring liquor, but it has been used in connection with grease recovery. When the liquor is treated with acid, the value of the potash product is greatly reduced, because the potassium is changed from the carbonate to the sulphate. The electrolytic regeneration of the acid with coincident production of caustic potash has been suggested for the acid liquors, but so far as known it has not been successful on a practical scale because of the high cost of the electric current required. The liquor resulting from washing wool after degreasing with volatile solvents and the waste liquor from the battage grease recovery can be utilized for potash recovery as in the case of steep liquor. Where concentration is used for grease recovery, the utilization of the concentrated waste for potash recovery is a very simple matter, for a little additional concentration, followed by calcination in a reverberatory furnace or in the ordinary rotary incinerator used for soda recovery in soda pulp mills produces a crude potash which has a substantial commercial value. Extraction of this crude product followed by concentration and calcination of the resulting liquor produces a high grade of potash.

Such treatment is a part of the patented Smith-Leach process, which is the highest development of utilization of wool-scouring liquor that has been put into practice. A plant using this complete process has been in practical operation for several years at the Field Head mills, Bradford, England.

The scouring liquor flows through settling tanks to remove the greater part of the sand and mud. From the tanks the liquor passes to a quadruple-effect Yaryan evaporator, which reduces it to one-tenth or one-fifteenth of its original volume. The condensed vapor from this machine provides distilled water of excellent quality for scouring purposes. After the concentrated liquor has been heated nearly to the boiling point, it is passed through a centrifugal separator, which separates it into an outer layer of sand and mud, a middle layer of soapy liquid containing all the potash, and an inner layer consisting almost entirely of wool grease. The sand and mud adhere to the separator and are removed from time to time by hand. The potash liquor and the wool grease are caught up separately and conveyed to separate receptacles. The wool grease is purified by warming it with water and allowing it to separate again by cooling. The potash liquor, which contains a large amount of fat combined as soap, is further concentrated to about one-fourth its volume, and it is then passed through a revolving cylindrical incinerator in which

the remaining water is evaporated and the organic matter is burned, leaving crude potassium carbonate. In this manner the scouring liquor is entirely disposed of and the following products are derived from it: Distilled water, wool grease, crude potassium carbonate, and sand and mud.

The distilled water is not perfectly pure, but contains small amounts of ammonia and grease, which have passed over during evaporation. The patentees claim that 15 to 30 per cent less soap is required in scouring when this distilled water is used. Moreover, the recovered water is at the temperature required for wool scouring. The wool grease is free from mineral and fatty acids, and it can be used without further purification as a lubricant or for any of the purposes for which Yorkshire grease finds a market. The potash salt contains from 50 to 70 per cent of pure potassium carbonate and it can be used in its crude state for wool scouring, or it can be sold for purification. The sand and mud removed by the separator are without market value. The advantages of the process are the entire destruction of the scouring liquor; the treatment of the suds in a fresh state, so that the whole process can be carried on without the production of the noxious odors so common in the ordinary cracking process; the comparatively small space occupied by the whole apparatus, and the profit which can be realized from the recovered products. The prominent disadvantages are the cost of installation for the evaporator and the coal consumption necessary for the vaporization of the water which the liquor contains. Table 11 shows the composition and the amounts of liquor at different steps in the Smith-Leach process as conducted at Field Head mills. The figures are computed from analyses by F. W. Richardson, and 1,000 gallons of liquor are used as a basis.

TABLE 11.—*Disposal of wool-scouring liquor at Smith-Leach plant of Field Head mills, England.*

Source.	Total amount of material.		Water.		Composition.				
					Total solids.	Grease.	Organic impurities.	Soluble mineral matter.	Insoluble mineral matter.
From evaporator:	*Galls.*	*Lbs.*	*Galls.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
Crude suds	1,000	8,452	970	8,100	352	174	78	73	27
Concentrated suds	103	959	73	607	352	174	76	63	39
Condensed water	897	7,493	897	7,493	.5	.4	0	.1	0
From separator:									
Grease	30	125	.6	5	120	118	.6	.....	1
Potash liquor	73	832	72	601	231	56	55	64	56
Earthy matter	0	2	0	.5	1.5	.2	0	0	1.3
	103	959	73	606	352	174	56	64	58
From evaporating incinerator:									
Crude potash	.....	94	0	0	94	.....	2	64	28
Loss	.....	738	72	601	137	56	53	0	28
	.....	832	72	601	231	56	55	64	56

The results of one week's operation of the plant at the Field Head mills are given in the following balance sheet. This record is adapted from the unpublished report of H. McLean Wilson, chief inspector of the West Riding rivers board, under whose direction the test of the plant was made. During the week of the test half of the wool washed was scoured wool. Consequently the waste liquor was very dilute and it forms an extremely conservative basis for estimates. Furthermore, the plant has double the capacity required for the amount of liquor treated and the fixed charges are therefore relatively high. The scouring liquor had presumably about the following composition in parts per million: Total solids 18,400 (volatile solids 13 100, fixed solids 5,300), fatty matters 8,900.

Balance sheet of Smith-Leach plant of Field Head mills, England, during week's test.

Cost of plant		$21,900
Amount of wool scoured	pounds	65,256
Amount of scouring liquor	gallons	66,000
VALUE OF PRODUCTS.		
3,300 pounds of wool fat	$146.00	
2,830 pounds of crude potash	93.98	
53,100 gallons of distilled water	6.69	
Soap saved by using above water—one-seventh total soap used	10.22	
		256.89
COST OF OPERATION.		
Coal, 19 tons (41,780 pounds)	50.54	
Labor, 3 men	16.60	
Interest and depreciation, 10 per cent	42.10	
		109.24
Profit		147.65
Profit per annum		7,677.80
Per cent of profit		35

The foregoing profits could not be realized in this country, owing to the greater cost of labor and the higher price of coal in the textile centers of the United States. The figures are of interest, however, for they show what has actually been done on a practical scale under adverse working conditions.

ECONOMY OF TREATMENT.

Reports of plants in operation in the United States indicate that the cracking and Turner-Akeroyd processes result in the recovery of sufficient grease to pay all costs of operation. In general, with the market value of recovered grease less than 2 cents a pound, the operations are conducted at a loss, but with higher values a profit is obtainable. The market value ranges from 1½ cents to 3½ cents, with a probable average of 2 cents a pound, so that little, if any, profit is to be expected from these processes under American conditions of practice.

A plant equipped for the Smith-Leach process and capable of utilizing 500 gallons of wool-scouring liquor an hour, ten hours a day, three hundred days a year, would cost approximately $13,000. The fixed charges of operation (interest, depreciation, and repairs) may be safely estimated at 11 per cent of the cost, or $1,430 a year. The cost of labor (3 men) would not exceed $1,650 a year. Fuel, 300 tons of coal at $4.50, allowing 10 per cent for banked fires fourteen hours daily, would amount to $1,350 a year if a triple-effect vacuum evaporator is used. If $200 a year is allowed for incidentals, the total cost of operation would amount to $4,630. In order to make the estimate more conservative, the costs may be placed at $5,000 a year, or $1 for each gallon of the daily capacity of the plant. In return for this expenditure, wool fat valued at 4½ cents a pound and crude potash worth 5 cents per pound of potassium carbonate content would be recovered.

The recoverable wool fat may be safely assumed to be 60 per cent of the fats indicated by analysis of the liquor. Numerous tests on the ash of scouring liquors indicate that the recoverable potash is equal to or greater than the potassium carbonate equivalent of the alkalinity of the liquor, and this equivalent may therefore be taken as a conservative estimate of the recoverable potash. The following estimate of costs, values, and profits, based on the foregoing facts and assumptions, has been made for treatment of the liquors represented by the analyses in Table 3 (p. 13). The numbers for the column headings have the same significance in both tables.

TABLE 12.—*Estimate of costs, values, and profits for application of Smith-Leach process to various wool-scouring liquors.*

	1.	2.	3.	4.	5.	Average (omitting 2).
Value of wool fat	$4,920	$19,920	$12,890	$10,680	$6,820	$8,830
Value of potash	6,920	6,920	2,680	3,300	2,460	3,840
	11,840	26,840	15,570	13,980	9,280	12,670
Cost	5,000	5,000	5,000	5,000	5,000	5,000
Profit	6,840	21,840	10,570	8,980	4,280	7,670
Per cent profit on investment of $13,000	53	168	81	69	33	59

Column 2 in Table 12 is calculated from an abnormal analysis, and estimates based on it were therefore omitted from the average. Column 5, representing the liquor treated at the Field Head mills in England, gives lower values than any other. The results previously given for a week's test at those mills indicate a 31 per cent profit from grease and potash under the working conditions—comparatively low labor costs and unnecessarily high cost of plant. The check obtained by this figure is an excellent one. It should be noted that in the test at the Field Head mills an additional 4 per cent profit is derived from the distilled water obtained and the soap saved through its use. This is an additional advantage of the process that is by no means negligible, although it has been omitted from Table 12 in order

that the estimates may be more conservative. If, as has been proved by several years' operation, the dilute liquors at the Field Head mills can be made to yield a profit, it is to be expected that the more concentrated liquors examined in the United States would give even better results. The average of 59 per cent profit, or $7,670 a year on an investment of $13,000, leaves a wide margin for marketing recovered products, and this is believed to be a conservative estimate. Larger plants could be operated even more economically, but smaller ones would necessarily be placed at a disadvantage because of relatively higher costs of maintenance. The effect of different concentrations of fat and potash in the liquors is shown in Table 12. Expressed in unit values, 385 parts per million of fat or 150 parts per million of alkalinity make a difference of 1 per cent in the estimated profits. The character of the wool scoured, and more especially the amount of water used in scouring it, influence the economy of treatment.

SUMMARY.

1. Wool is impregnated with many impurities which must be removed before it can be used in the manufacture of textiles.

2. The common methods of cleansing wool are: (*a*) Scouring with soap, alkali, and water; (*b*) steeping and scouring; and (*c*) scouring with volatile solvents. Such treatment produces great quantities of foul liquors containing valuable substances, which can usually be recovered profitably with coincident purification of the liquors.

3. The scouring liquor most frequently encountered in the United States is the waste suds from scouring with soap, alkali, and water. Purification of this liquor by the usual methods of sewage treatment is difficult at best and usually impracticable. Purification combined with recovery of grease or potash is possible and can generally be accomplished at little or no expense. The degree of purification and the coincident profit on the capital invested for three prominent systems of treatment are shown in Table 13.

TABLE 13.—*Degree of purification and profit of different methods of treating wool-scouring liquor.*

	Per cent purification.			Per cent profit on capital invested.
	Total solids.	Volatile solids.	Fats.	
Cracking process	65	75	83	0
Turner-Akeroyd process (including filtration)	48	97	98	0
Turner-Akeroyd process (excluding filtration)			92	0
Smith-Leach process	100	100	100	59

4. All the evidence gathered tends to show that wool-scouring liquor can be entirely destroyed by means of the Smith-Leach process, and that sufficient valuable products can be recovered therefrom to pay all costs of treatment and leave a substantial profit on the capital invested.

BLEACHING AND DYEING COTTON YARN.

BLEACHING PROCESSES AND WASTE WATERS

The methods of bleaching and dyeing cotton yarn do not differ in essential principles from those of bleaching and dyeing other cotton goods, but the form of the material and its condition with respect to impurities render the processes more or less distinctive.

Gray boil.—The yarn when brought to the bleachery contains dirt that has accumulated during transportation as well as other impurities that must be removed before bleaching. The first process is cleansing in the gray boil. The yarn is placed by hand in closed iron kiers, after which water and steam are admitted. The desired amount of alkali, usually sufficient to make a 0.5 to 1 per cent solution of caustic soda, is then added, and boiling with open steam pipes is continued for ten or twelve hours. The kiers are so designed that the solution circulates through the yarn, and an open steam exhaust keeps the pressure very low. The natural impurities, including cotton wax, margaric acid, pectic acid, parapectic acid, and albuminous matters, and constituting from 3 to 5 per cent of the weight of the yarn, are emulsified and dissolved by boiling in the dilute alkaline solution, which does not appreciably affect the cotton fiber. At the end of the boil the liquor is drawn off and the yarn is thoroughly rinsed with fresh water.

Bleaching.—After it has been rinsed and drained the yarn is removed from the kiers and placed in stone or concrete vats. Bleaching or "chemic" solution, usually chloride of lime of a strength represented by a specific gravity of 1.01 (2° Twaddell, or 1.5° Baumé), is added until the yarn is covered. The material is steeped for a period of two to four hours, and the solution is drained off and returned to storage tanks for further use. The steeped yarn is then rinsed by covering it with water and draining; two such rinsings are usually given in order to remove excess of chemic solution. A weak acid, or "sour" solution, usually sulphuric acid of 1.005 specific gravity (1° Twaddell, or 0.75° Baumé), is then admitted in sufficient quantity to cover the yarn. The chemic solution remaining in the material reacts with the acid, and bleaching by oxidation results. After steeping a few hours, the acid is drawn into a storage tank and held for further use.

Cotton fiber has the property of concentrating within itself acid from a solution; furthermore, it is sensitive to acid and easily injured by it; for these reasons, and also in order to prevent additional and uncontrolled bleaching action, the material must be cleansed from all traces of acid at this stage. This is accomplished by three successive rinsings with fresh water in the masonry vats and by "soaping," which is customarily done by hanging the skeins of yarn on wooden

sticks and moving them by hand through narrow wooden vats which contain dilute soap solution. The soap effectually neutralizes any remaining acid and leaves the fiber in proper condition. A final rinsing in clear water in similar vats removes the excess of soap from the yarn. The soaping and rinsing may be effected by means of revolving wheels on which the sticks bearing skeins of yarn are fastened like the cars on a Ferris wheel. Partial drying in centrifugal machines, drying by heat, and winding on spools are the finishing processes.

Wastes.—The waste waters from the bleaching processes are described in the following paragraphs. The estimates of quantity of the different materials are based on the treatment of 1 ton of yarn.

Waste A, gray-boil liquor: Usually 250 to 1,000 gallons in amount, with an average of 600 gallons; contains 25 to 30 pounds of sodium compounds expressed in terms of caustic soda and 60 to 75 pounds of impurities from the cotton; reddish brown or garnet in color and has a characteristic odor like that of burnt sugar.

Waste B, gray-boil rinse: Amounts to about 3,000 gallons; contains about 10 to 15 pounds of sodium compounds and 25 to 40 pounds of impurities from the cotton; in reality a diluted portion of waste A. As the rinsing is usually accomplished by a continuous stream of water, this waste varies in character from a concentration nearly equal to that of waste A to nearly pure water.

Waste C, first chemic rinse: About 1,000 gallons in amount; contains small quantities of sodium compounds and cotton impurities and comparatively large amounts of calcium chloride, some sulphates, and some free chlorine, giving total solids of 10 to 15 pounds; characterized by a strong chlorine odor.

Waste D, second chemic rinse: Similar to waste C in quantity and in quality except that it is much more dilute, containing only about one-fifth as much matter in solution.

Waste E, first sour rinse: Amounts to about 1,000 gallons, like the other sour rinse waters and the chemic rinses; has a slight odor of chlorine and contains 20 to 25 pounds of free acid and 10 to 15 pounds of calcium sulphate; other impurities are small in amount.

Waste F, second sour rinse: Practically a dilution of waste E; character determined by the quality of water used for rinsing, from which it differs by having a slightly lower alkalinity and a somewhat increased sulphate content.

Waste G, third sour rinse: Similar to waste F.

Waste H, soap liquor: Amounts to about 4,500 to 5,000 gallons; light blue in color by reason of the addition of a small amount of bluing to whiten the goods; has a characteristic soapy appearance, with high turbidity, alkalinity, and fat content, 30 to 40 pounds of soap having been used.

Waste I, soap rinse: Same in quantity as waste H, of which it is a dilution; contains one-fifth to one-tenth as much soap and organic matter as waste H and is too dilute to warrant much consideration.

Waste J, lime sludge: Chloride of lime is agitated with water in cement-lined tanks in order to prepare the bleaching solution. As the chloride of lime is never pure, an insoluble sludge collects at the bottom of the tanks and is removed periodically. The sludge is semi-liquid in consistency and contains chlorides, hypochlorites, hydrates, carbonates, and sulphates of calcium, together with small amounts of other substances. The amount of sludge is 30 to 50 pounds, varying in quantity and in consistency with the quality of bleaching powder and with minor changes in manipulation.

An excellent opportunity was afforded the writers to study the processes and waste waters from the bleaching and dyeing of cotton yarn at the establishment of the R. D. Mason Company, Pawtucket, R. I.

Table 14 shows the character of the wastes from cotton-yarn bleaching at this establishment. Wastes A, B, E, and H are the most objectionable.

TABLE 14.—*Character of waste liquors from bleachery of the R. D. Mason Company, Pawtucket, R. I.*[a]

[Milligrams per liter, unless otherwise stated.]

	Waste A (gray-boil liquor).	Waste C (first chemic rinse).	Waste D (second chemic rinse).	Waste E (first sour rinse).	Waste F (second sour rinse).	Waste G (third sour rinse).	Waste H (soap liquor).	Waste I (soap rinse).
Date, 1907	Mar. 7	Feb. 21	Feb. 21	Feb. 21	Feb. 21	Feb. 21	Feb. 21	Feb. 21
Amount in gallons	2,400	3,200	3,200	3,200	3,200	3,200	14,000	15,000
Color	Orange.	21	28	12	21	21	Light blue.	Slight soapy.
Odor	Burnt sugar.	Chlorine.	Slight chlorine.	Slight chlorine.	None.	None.	Soap and chlorine.	Soap.
Turbidity	650	10	5	5	5	5	400	50
Sediment	Considerable.	Considerable.	Very slight.	Slight.	Slight.	Slight.	Slight.	Very slight.
Oxygen consumed	4,400	17.5	3.5	9.2	1.7	1.5	84	12
Nitrogen as free ammonia	6.5	.17	.05	.02	.05	.04	.25	.15
Organic nitrogen	234	1.00	.50	1.00	.35	.30	2.00	.90
Chlorine	260	635	72	70	24	24	34	20
Alkalinity as $CaCO_3$	440	Slight.	Slight.	[b] 2,790	30	30	345	53
Sulphate radicle (SO_4)	360	408	78	3,800	47	44	60	54
Fats	3,520						380	46
Total solids	17,920							
Loss on ignition	9,320							

[a] Analyses by Pratt and Stabler. [b] Acid.

DYEING PROCESSES AND WASTE WATERS.

Wet-out process.—Though cotton yarn must be cleansed before it can be satisfactorily dyed, dyeing does not always require so thorough a preliminary treatment of the yarn as bleaching does. The cleansing process, or "wet out," is conducted in kiers like those used for the gray boil before bleaching. The yarn is piled in these kiers and boiled

with water and steam but without chemicals for about six hours. After the boiling has been completed, the material is rinsed in the kiers and then allowed to drain for several hours, after which it is ready for dyeing. For some colors, the entire bleaching process may be substituted for the wet-out boil.

Dyeing.—Dyeing operations are many and varied, and they are usually conducted in the form of apparatus described for the soaping process in bleaching. Machines are generally employed for heavy colors, and the dye baths are saved for further use. The lighter colors are more often applied by the hand process, and the baths are discharged after having been used but once. The following abstracts from Thorp's text-book [a] give some idea of the varied character of the liquors discharged from a dyehouse for cotton yarn.

Direct dyes, or those which yield full colors without the assistance of mordants, are applied in a boiling bath usually with 10 to 15 per cent of common salt or Glauber's salt. Ingrain colors require in addition "diazotizing" in a cold bath of sodium nitrite acidulated with hydrochloric acid, and "developing" by treatment with phenols, naphthols, or amines. Basic dyes, or those which form insoluble tannates and require mordants on vegetable fibers, are the salts of colorless bases. The cotton is first mordanted in a bath of tannin, turkey-red oil, or soap, and it is then treated in a bath of the dyestuff. The base of the dyestuff combines with the acid of the mordant to form the color, and the goods are not washed after having been dyed. Acid dyes are applied in a very concentrated bath to which common salt, acetic acid, and alum are added, or the yarn may be first mordanted in a bath of alum and soda or of stannic chloride followed by alum and soda. Tannin treatment may precede mordanting with alum and soda. Mordant dyes for cotton are chiefly turkey reds, logwood blacks, and alizarin colors, and they always require a metallic mordant, such as the salts of aluminum and less frequently those of chromium, iron, and tin. Oil, sodium carbonate, powdered chalk, sodium phosphate, sodium arsenate, and calcium acetate are some of the accessory chemicals that may be used in the processes. After having been dyed, the yarn may be subjected to soap baths. Special dyes include those colors which are prepared or developed directly on the fiber by peculiar processes and include indigo, aniline black, and certain azo colors. The baths may contain sodium hyposulphite, copperas, zinc compounds, milk of lime, potassium bichromate, copper salts, potassium ferrocyanide, and many other chemicals.

Wastes.—Any or all of the classes of dyes mentioned above may be applied in a dyehouse during a single day, or one class may be used

[a] Thorp, F. H., Outlines of industrial chemistry, 1901, pp. 482–494.

one day and another the next. It is impossible, therefore, to predict the nature or the color of the liquor in a dyehouse sewer. Average results for a day's run offer the best opportunity for comparisons, but even these may vary widely from day to day. The quantity of liquor discharged also varies considerably, as one bath may suffice for fixing some colors, while seven or eight baths may be required for fixing others. The waste liquors from a cotton-yarn dyehouse may be classed under three heads, as follows:

Waste K, wet-out liquor: Orange colored; has a peculiar odor like that of scorched vegetable matter, and contains a large amount (about 3 per cent by weight of the yarn) of the impurities, chiefly organic, removed from the fiber; in quantity it averages about 600 gallons per ton of yarn. Similar in many respects to waste A. (See p. 28.)

Waste L, wet-out rinse: A dilution of waste K, concentrated at first, but becoming more nearly pure water as the rinsing progresses; usually amounts to from 2,500 to 3,000 gallons and contains 10 to 20 pounds of impurities per ton of yarn.

Waste M, sewage from dyeing processes: Of extremely varied character; changes color at frequent intervals and varies in reaction from strongly acid to excessively alkaline. The quantity may be roughly estimated at 20,000 to 30,000 gallons per ton of yarn, and the content of impurities at from 250 to 400 pounds of dyes, and other chemicals per ton of yarn.

The following table shows the general characteristics of waste K and the nature of waste M for one day at a yarn dyehouse:

TABLE 15.—*Character of waste liquors at cotton dyehouse of the R. D. Mason Company, Pawtucket, R. I.*[a]

[Milligrams per liter.]

	Waste K ("wet-out" liquor).	Waste M (dyehouse sewage).
Date, 1907	Mar. 7.	Mar. 6.[b]
Amount.....gallons.	2,400	90,000
Color	Orange.	Red to purple.
Odor	Scorched vegetable matter.	Dyes.
Turbidity	70	300
Sediment	Considerable.	Heavy.
Oxygen consumed	1,140	240
Nitrogen as free ammonia	7.2	1.8
Organic nitrogen	106	5.25
Chlorine	115	250
Alkalinity as $CaCO_3$	400	40
Sulphate radicle (SO_4)	120	530
Fats	429	27
Starch	Present.	.....
Total solids	4,430	1,470
Loss on ignition	2,860	450

[a] Analyses by Pratt and Stabler.

[b] Composite.

PURIFICATION OF WASTE WATERS.

PREVIOUS INVESTIGATIONS.

Experimental treatment by the Massachusetts state board of health[a] of a composite liquor composed of six of the most objectionable wastes from the processes of dyeing, bleaching, and mercerizing cotton yarn, mixed in proportion to the quantity of each waste, showed that about 87 to 90 per cent removal of organic matter was effected by sand filtration, and that about 92 to 93 per cent removal was obtained by the use of chemical precipitants followed by sand filtration. Though the waste was a very turbid brown liquor, the effluents were straw colored. A rate of 50,000 gallons per acre per day was used in the work.

Experimental work on waste dye liquors from a woolen mill was also conducted.[b] While this waste is not derived from the industry under discussion, it seems proper to mention here the general conclusions reached, as follows: The waste dye liquor from a woolen mill can be sucessfully treated by sand filtration at sewage rates; a large part of the color will be removed, but more surface raking is required than is necessary with sewage. The addition of copperas followed by lime in amounts averaging about one-half ton each for 1,000,000 gallons will effect good color removal when the liquor is allowed to settle about one hour; the resulting supernatant liquor can be filtered through sand at rates approximating 2,000,000 gallons per acre per day with good results. The sludge will be about 1.5 per cent of the volume of the liquor treated and can be satisfactorily filtered at a rate of 40,000 to 50,000 gallons per acre.

Though the wastes from a cloth dyeing and finishing works at Ravenna, Ohio, studied by Stabler,[c] were liquors from dyeing wool, they resemble those under discussion sufficiently to justify mention. His work indicated that for chemical precipitation of such liquors lime and copperas together gave better purification at less cost than either alone. Separate treatment of the concentrated dye wastes was more economical than treatment with the rinse water, "crab" waste, and a waste from washing and dyeing wool. Straining these four combined through sifted coke breeze at a rate of 520,000 gallons per acre per day removed from one-third to one-half the organic matter present. Results from the operation of an experimental plant at Ravenna confirmed the conclusion drawn from laboratory tests on the use of lime and copperas as precipitants, and indicated

[a] Thirty-eighth Ann. Rept. Massachusetts State Board Health, 1906, p. 301.

[b] Thirty-fifth Ann. Rept. Massachusetts State Board Health, 1903, p. 271.

[c] Stabler, Herman, Disposal of waste water from cloth dyeing and finishing works at Ravenna, Ohio. Ohio Sanitary Bull., vol. 10, 1906, p. 189.

that the combined wastes were fairly well purified when treated with 12 pounds of copperas and from 8 to 10 pounds of lime per 1,000 gallons, at a cost of about 7½ cents. The concentrated dye waste, taken alone, showed about 70 per cent removal of organic matter when treated with 42 pounds of copperas and 15.8 pounds of lime per 1,000 gallons, at a cost of about 23 cents.

LABORATORY EXPERIMENTS.

Several experiments, which were not refined in detail, were made in the laboratory by the writers on liquors from the Mason establishment. Waste A, the gray-boil liquor, was treated with different amounts of sulphuric acid. Complete coagulation was most nearly obtained by using 58 pounds of sulphuric acid per 1,000 gallons. The liquor became clear in about two minutes and the coagulum, probably a very impure pectic acid, was reduced in half an hour to 5.6 per cent, by volume, of the original liquor. Analyses before and after treatment showed the following results:

TABLE 16.—*Analyses of waste A before and after treatment with sulphuric acid.*[a]

[Milligrams per liter.]

	Before treatment.	After treatment.
Oxygen consumed	4,400	3,320
Organic nitrogen and nitrogen as free ammonia	240	156
Fats (ether-soluble matter)	3,520	2,050
Alkalinity as $CaCO_3$	440	−3,500
Sulphate radicle (SO_4)	360	7,900
Total solids	17,920	20,280
Loss on ignition	9,320	9,580

[a] Analyses by Pratt and Stabler.

These analyses do not show great improvement in the quality of the liquor, though there is a decided reduction in oxygen consumed, nitrogen, and fatty matters. The dried coagulum was largely volatile, 96.6 per cent being lost on ignition. Less visible purification was procured by the use of greater or less amounts of acid and by the substitution of hydrochloric for sulphuric acid. The substance removed by this coagulation contained much coloring matter, and was readily soluble in alkaline solutions, especially solutions of the caustic alkalies.

Equal parts of waste A, the gray-boil liquor, and waste K, the "wet-out" liquor, were treated with sulphuric acid in the ratio of 58 pounds of the acid to 1,000 gallons of waste. The coagulum gathered and the liquor cleared as in the preceding experiment. The following

analyses show, as would be anticipated, that the relative purification is similar to that of the former experiment; 98.1 per cent of the dried coagulum was lost on ignition:

TABLE 17.—*Analyses of wastes A and K (mixed) before and after treatment with sulphuric acid.*[a]

[Milligrams per liter.]

	Before treatment.	After treatment.
Oxygen consumed	2,770	1,720
Organic nitrogen and nitrogen as free ammonia	177	113
Fats (ether-soluble matter)	1,975	1,370
Alkalinity as $CaCO_3$	420	−3,750
Sulphate radicle (SO_4)	240	7,200
Total solids	11,180	13,400
Loss on ignition	6,090	6,590

[a] Analyses by Pratt and Stabler.

Waste E, the first sour rinse, and waste H, the soap liquor, were combined in the proportion in which they occur in the bleachery, 1 part of the former to 4.38 parts of the latter. The result was a coagulation of the soap. The following analyses of the combined liquors and the filtrate after coagulation disclose very decided purification of both wastes:

TABLE 18.—*Results of mixing wastes E and H.*[a]

[Milligrams per liter.]

	Combined liquors.	Filtrate.
Color	Light blue.	15
Turbidity	330	0
Oxygen consumed	70	23.2
Organic nitrogen and nitrogen as free ammonia	2.02	1.75
Fats	310	12
Acidity as $CaCO_3$	240	260

[a] Analyses by Pratt and Stabler.

Waste M, the dyehouse sewage, was treated with milk of lime at the rate of 2½ pounds per 1,000 gallons (17.5 grains per United States gallon) and 3⅓ pounds per 1,000 gallons (23.3 grains per United States gallon). The former mixture was filtered after standing sixteen hours, and the latter after standing five hours, and the filtrates were both subjected to analysis, with results as shown in Table 19.

TABLE 19.—*Results of treating waste M with lime.*[a]

[Milligrams per liter.]

	Waste M (dyehouse sewage).	After treatment with 2½ pounds of lime per 1,000 gallons, and after 16 hours' sedimentation.	After treatment with 3¾ pounds of lime per 1,000 gallons, and after 5 hours' sedimentation.
Color	Reddish purple.	Light straw.	Very light straw.
Turbidity	300	0	0
Sulphate radicle (SO_4)	530	350	350
Alkalinity as $CaCO_3$	40	124	80
Oxygen consumed	240	102	99
Organic nitrogen and nitrogen as free ammonia	7.05	3.25	3.45

[a] Analyses by Pratt and Stabler.

The color of the filtrates faded on standing. Both parts of the experiment show very good decolorization and removal of more than 50 per cent of the organic matter. The lower percentage of lime, with longer time for reaction and sedimentation, seems to give fully as good results as the second treatment.

No experiments were made with the lime sludge, waste J. It is a precipitant of great value and could doubtless be used in place of lime in a precipitation plant, thus reducing the cost of chemicals and disposing of an additional waste.

EXPERIMENTS AT PAWTUCKET, R. I.

Waste M, the liquor causing most serious pollution from the R. D. Mason plant, except the bleach-house boils, is discharged through the dyehouse drain. Filtration experiments having been started at another plant with kier liquors (see p. 47), the work at this plant was confined to the wastes from the dyeing processes, the wet-out liquor, however, not being included in samples taken or applied to the filters, as it was discharged very early in the morning.

Character of wastes.—The liquors which are discharged from the dyeing processes at this establishment are typical. They are disagreeable to look at, on account of the coloring matter in them, and they exert an influence on the stream into which they are discharged which is objectionable not only because of the unsightly appearance but also because of the organic matter and chemicals which they contain in solution. Samples of the liquor taken at different times have shown, as would be expected, great variations in its quality, the colors varying between the widest extremes and the organic and mineral contents showing similar fluctuations. A fairly accurate conception of the average character of the liquor with which experiments were made can be obtained from the analysis of the composite sample, given in line 1 of Table 20. The analyses of nine samples of the dye water,

collected on different days between October 10, 1907, and January 18, 1908, are also given in this table, and they show great variation in results; but an average of them, as shown by line 11, represents a liquor of nearly the same strength as the composite sample.

TABLE 20.—*Analyses of liquor from dye drain of R. D. Mason Company.*[a]

[Milligrams per liter, unless otherwise satted.]

Sample No.	Date.	Oxygen consumed.	Nitrogen as free ammonia.	Organic nitrogen.		Solids.		Loss on ignition.		Number of bacteria per cubic centimeter.
				Total.	Dissolved.	Total.	Dissolved.	Total.	Dissolved.	
	1907.									
1	Mar. 6	240	1.8	5.2	.....	1,470	.....	450	.....	.....
2	Oct. 10	102	1.3	2.9	2.4	1,140	1,092	206	168	Very high.
3	Oct. 17	144	.3	1.3	.....	790	612	356	182	20,000
4	Oct. 31	257	1.4	6.4	4.8	906	782	426	340	100,000
5	Nov. 8	85	1.0	2.7	1.5	1,576	1,482	262	248	.....
6	Nov. 21	155	1.0	1.0	.....	570	.....	290	.....	40,000
7	Dec. 20	354	1.0	3.5	.....	1,174	.....	764	.....	Less than 10,000.
	1908.									
8	Jan. 3	194	.7	1.8	.....	.....	.....	.....	.....	740,000
9	Jan. 10	660	4.9	2.5	.....	.....	.....	.....	.....	5,000
10	Jan. 18	218	.7	15.5	.....	.....	.....	.....	.....	Less than 10,000.
11	.....	241	1.4	4.1	.....	.....	.....	.....	.....	.....

[a] Analyses by G. H. Pratt.

1. Composite of samples taken every half hour from 9 a. m. to 5.30 p. m.
2 to 10, inclusive. Single samples taken between 10 a. m. and 11.45 a. m., at time when filters were dosed.
11. Average of 2 to 10, inclusive.

Sand filters.—It was decided to study the results which could be obtained by applying this waste dye liquor to sand filters. The applied liquor was not selected with special reference to its appearance or composition, but was generally drawn directly from the dyehouse effluent when the attendant was ready to dose the filters. In case the effluent appeared very dilute, however, the dosing was postponed a few minutes until a normal sample could be taken. Two galvanized iron filters were installed, each 6 feet high and 20 inches in diameter, with slightly inclined bottoms to permit thorough draining through faucets at the lowest level. Underdrainage was provided by a foot of coarse cinders overlain by 10 inches of crushed stone approximately the size of pea coal. The filtering material was 3½ to 4 feet of sand, having an effective size of 0.24 millimeter and a uniformity coefficient of 3.4. The filters were set up in the yard and were subject to all effects of the weather.

Effluents.—Filter No. 1 was started on October 1, 1907, with a dose of 5 gallons a day, or at the rate of 100,000 gallons per acre per day, six days in the week, and that size of dose was continued till November 22. During this time the filter delivered an effluent of extremely good appearance, free from color due to dyes (average reading = 48), and low in organic content as shown by analysis. (See Table 21.)

TABLE 21.—*Analyses of effluent from filter No. 1 treating dye liquor.*[a]

[Milligrams per liter, unless otherwise stated.]

Sample.	Date.	Color.	Oxygen consumed.	Nitrogen as free ammonia.	Organic nitrogen.	Nitrogen as nitrates.	Nitrogen as nitrites.	Chlorine.	Alkalinity as $CaCO_3$.	Total solids.	Loss on ignition.	Number of bacteria per cubic centimeter.	Rate of filtration (gallons per acre per day)
	1907.												
1	Oct. 10	75	9.6	1.65	0.47	.....	0.008	.....	.....	796	211	2,250	100,000
2	Oct. 17	85	7.2	.65	.64	0.50	.176	.....	.....	1,001	87	800	100,000
3	Oct. 31	18	5.0	.80	.20	.08	.032	82	....	493	61	73,000	100,000
4	Nov. 8	32	4.6	.80	.29	.05	.016	56	16	696	82	.....	100,000
5	Nov. 21	30	5.5	.16	.23	.22	.011	106	21	524	64	36,700	100,000
6	Dec. 13	Wine.....	20.0	.16	.64	Present.	Present.	....	....	501	74	60,000	400,000
7	Dec. 20	Brownish wine...	140.0	1.36	1.54	Present.	.100	...	0	1,143	348	50,000	400,000
	1908.												
8	Jan. 3	Dark brown.....	99.2	.44	1.50	.....	.100	....	20	.....	....	50,000	400,000
9	Jan. 10	Dark reddish brown.....	84.0	.49	1.85	Present.	4.000	....	.....	.....	....	10,000	100,000
10	Jan. 18	Light brown.....	22.8	.18	1.38	1.75	.700	....	.....	.....	....	10,000	100,000
11	Feb. 21	Violet.....	42.0	.26	1.20	.70	.020	....	.....	.....	....	.....	100,000
12	.....	.....	6.4	.81	.37	.....	.....	.....	.....	.....	.....	.....	.....

[a] Analyses by G. H. Pratt.

1 to 11, inclusive, represent single samples taken between 10 a. m. and 12 m.
12. Average of 1 to 5, inclusive.

From November 22 to January 4 the filter was dosed at the rate of approximately 400,000 gallons per acre per day, and the combined effect of cold weather and the increased rate caused the effluent to show color; from December 13 until the last dosing on February 21 the effluent was not of good appearance, nor did it give a satisfactory analysis, though from January 4 until the filter was stopped the dose was the same as originally—100,000 gallons per acre daily. The exposure of the cans to extremely cold weather probably had an appreciable influence on the work of the filter during the latter part of the run. The fact that the experimental filters were entirely above ground allowed much greater chilling effects on their contents than would occur in a plant where only the tops are exposed. The surface of neither filter was raked during the run, but the sand was leveled two or three times. The detailed analyses of the effluent from filter No. 1 are given in Table 21.

Filter No. 2 was a duplicate of No. 1 as to construction and filtering material. It was started at the same time, October 1, 1907, at the rate of approximately 200,000 gallons per acre per day, and this rate was continued throughout the run of the filter. The same deterioration in quality and appearance of the effluent during extremely cold weather was noticed, and it is probable that to the excessive exposure of the cylinders, to which reference has been made, were due largely the comparatively poor results obtained during the latter part of the run. For the purpose of comparison, therefore, it seems best to select the results obtained during the same period used for figuring on filter No. 1—that is, from October 1 through November 21.

During this period the filter gave an effluent of fairly good appearance, at times even lower in color than that from No. 1, but a little color from the dyes seemed to pass through it always, and sometimes the shade was marked. The figures for organic nitrogen and oxygen consumed were higher on this filter, as would be expected at the higher rate.

TABLE 22.—*Analyses showing organic purification of dye liquor by filtration.*[a]

Source.	Milligrams per liter.			Per cent removal.		
	Nitrogen as free ammonia.	Organic nitrogen.	Oxygen consumed.	Nitrogen as free ammonia.	Organic nitrogen.	Oxygen consumed.
Waste from dye drain	1.80	5.21	240			
Average of 5 analyses of effluent from filter No. 1, when run at 100,000-gallon rate	.81	.37	6.4	55	93	97
Average of 5 analyses of effluent from filter No. 2, when run at 200,000-gallon rate	.89	.67	11.8	51	87	95

[a] Analyses by G. H. Pratt.

The effluents from both filters always contained nitrites, but the nitrates were never high, although they were always present to some extent. The percentage of removal effected by filter No. 1 at the 100,000-gallon rate and by filter No. 2 at the 200,000-gallon rate on nitrogen as free ammonia, organic nitrogen, and oxygen consumed is shown in Table 22, for which the analysis of the composite sample of March 6 (line 1, Table 20) has been used as a basis for calculating percentage removal.

Detailed analyses of the effluent from filter No. 2 are shown in Table 23.

TABLE 23.—*Analyses of effluent from filter No. 2 treating dye liquor.*[a]

[Milligrams per liter, unless otherwise stated.]

Sample.	Date.	Color.	Oxygen consumed.	Nitrogen as free ammonia.	Organic nitrogen.	Nitrogen as nitrates.	Nitrogen as nitrites.	Chlorine.	Alkalinity as $CaCO_3$.	Total solids.	Loss on ignition.	Number of bacteria per cubic centimeter.	Rate of filtration (gallons per acre per day).
	1907.												
1	Oct. 10	47	3.2	2.45	0.43	(?)0.05	0.044	.....	.....	712	133	15,000	200,000
2	Oct. 17	35	6.2	.89	.48	.40	.160	.....	.....	1,030	68	5,000	200,000
3	Oct. 31	L. purple.	28.5	.56	1.53	(?)	.200	72	.....	597	92	158,000	200,000
4	Nov. 8	45	8.9	.50	.46	.14	.140	82	31	764	110	.....	200,000
5	Nov. 21	40	12.2	.07	.47	.38	.026	208	30	676	81	69,000	200,000
6	Dec. 13	Wine.	27.2	.13	.56	Present.	Present.	.....	.....	743	74	100,000	200,000
7	Dec. 20	Brownish.	83.0	.61	1.67	Present.	1.000	.....	22	700	223	25,000	200,000
	1908.												
8	Jan. 3	D. brown.	68.8	.21	.93	Present.	.140	.....	20	.....	.....	10,000	200,000
9	Jan. 10	D.y.brown.	85.0	.64	1.95	Present.	4.000	.....	.....	.....	.....	25,000	200,000
10	Jan. 18	D.p.brown.	28.0	.28	1.62	1.85	1.200	.....	.....	.....	.....	5,000	200,000
11	Feb. 21	Violet.	46.0	.20	1.25	1.00	2.500	.....	.....	.....	.....	.....	200,000
12	.....	.....	11.8	.89	.67	.....	.....	.....	.....	.....	.....	.....	200,000

[a] Analyses by G. H. Pratt.

1 to 11, inclusive, represent single samples taken between 10 a. m. and 12 m.
12. Average of 1 to 5, inclusive.

Effect on sand in filters.—When the plant was dismantled on March 5, 1908, the sand in the filters was sampled at the top inch, 6 inches down, 2 feet down, and just above the crushed stone. The sand was not at all clogged, nor had it become so at any time during the run, but it was badly discolored for about 6 inches down, and discolored channels ran through the rest of the bed, though the larger part of the main body had apparently not been affected in color. The results of determining albuminoid ammonia and loss on ignition on the samples of sand, given in Table 24, show that even the surface sand was not extremely high in stored organic matter, and that it would have been suitable for a much longer run without being replaced.

TABLE 24.—*Analyses showing albuminoid ammonia and loss on ignition of filter sands.*[a]

Sand from filter No. 1.			Sand from filter No. 2.		
Source.	Albuminoid ammonia.	Loss on ignition.	Source.	Albuminoid ammonia.	Loss on ignition.
	Parts per million.	*Per cent.*		*Parts per million.*	*Per cent.*
Top inch	71	1.31	Top inch	65	1.10
6 inches down	19	.42	6 inches down	19	.44
2 feet down	15	.37	2 feet down	14	.37
Bottom	12	.38	Bottom	8	.32

[a] Analyses by G. H. Pratt.

COST OF TREATMENT.

The following estimate, indicating the approximate cost of treating the dyehouse waste by sand filtration at the rate of 100,000 gallons per acre per day, is based on a flow of 100,000 gallons a day:

Estimated cost of sand filtration of dyehouse waste.

Cost of plant (flushing tank with automatic regulator and 1 acre of filtration beds)	$5,000
Annual cost of maintenance:	
Interest on $5,000 at 5 per cent	250
Depreciation and repairs at 8 per cent	400
Labor	160
	810

Another estimate has been prepared on the assumption that the laboratory experiments with lime precipitation are a fair index of practical treatment of the waste in a plant similar to the apparatus used for water softening or for mechanical filtration of water.

Estimated cost of purification of dyehouse waste by lime precipitation.

Cost of plant (apparatus for chemical treatment, sedimentation, and filtration; pump; and sludge beds, with total area of about 400 square feet)	$4,000
Annual cost of maintenance:	
Interest on $4,000, at 5 per cent	200
Depreciation and repairs, at 10 per cent	400
Pumping, at 0.25 cent per 1,000 gallons	75
Labor	75
Lime, at $6 a ton (treatment at rate of 3 pounds per 1,000 gallons)	270
	1,020

These figures indicate that the choice between the two methods of treatment, so far as cost is concerned, is determined by the area available. Mechanical treatment can be conducted on one-tenth the area necessary for sand filtration, and this is a distinct advantage in an urban community, because it appreciably reduces the cost of installation and interest. The effluent from the sand filter, however, is decidedly better in quality, showing a removal of over 90 per cent of the organic matter, as against a removal of little more than 50 per cent by the mechanical plant. The effluent from a plant of either style is satisfactory in color, which is the first requisite in purification of a dye liquor. Sand filtration at the rate of 200,000 gallons per acre per day would reduce the cost of the plant by 50 per cent and would make the annual cost of maintenance less than $500. The combined factors of reduced area and lower cost of maintenance under such conditions indicate that sand filtration is usually the most desirable method of treatment. Local conditions as to area obtainable and final disposal of effluent, however, necessarily determine whether the waste liquor from a yarn dyehouse can be purified most advantageously in a mechanical plant, by means of sand filters, or by a combination of the methods.

The conclusions drawn from these investigations are in accord with those of a previous less detailed study by the Rhode Island state board of health of the dyehouse waste from the R. D. Mason mill, possibly mixed at times with bleach-house waste. They are also consistent with the work of other investigators, though the proposed rates of filtration are somewhat higher.

SUMMARY.

1. Waste waters from dyeing cotton yarn can be satisfactorily purified by filtration through sand. If the rate of filtration is 100,000 gallons per acre per day, six days a week, 90 to 97 per cent of the organic matter and practically all color can be removed from the liquor with an investment of $50 (not including cost of land) and at an

annual cost (including interest, depreciation, repairs, and labor) of $8.10 per 1,000 gallons per day. If the rate of filtration is doubled, 85 to 95 per cent of the organic matter can be removed and color can usually be reduced to a satisfactory extent, though this item will vary somewhat with changes of temperature in the filtering medium and changes of intensity of color in the applied waste. The investment of the annual cost for such purification would be, respectively, $25 and $4.50 per 1,000 gallons per day.

2. Laboratory experiments indicate that 50 to 60 per cent of the organic matter and all the objectionable color can be removed from the waste waters by precipitation with about 3 pounds of lime per 1,000 gallons (21 grains per gallon). A mechanical plant operating by this method would cost $40, and would require an annual outlay (including interest, depreciation, repairs, pumping, chemicals, and labor) of about $10.20 per 1,000 gallons per day.

3. Laboratory experiments indicate that yarn-bleaching liquors may be purified. Gray-boil liquor treated with sulphuric acid and filtered loses about 35 per cent of its organic matter, but the cost of treatment is relatively very high for the benefits derived. Similar results are indicated for a mixture of gray-boil and wet-out liquors. Filtration or sedimentation of mixed soap liquors and sour-rinse water produces a highly purified effluent.

BLEACHING COTTON PIECE GOODS.

BLEACHING PROCESSES AND WASTE WATERS.

The routine processes in a cotton-goods bleachery are described below. These processes, however, are followed only in a general way at Saylesville, where the writers conducted investigations, for there, as at other progressive bleacheries, experience has suggested many modifications of detail and of apparatus.

The pieces of goods, having first been marked for identification, are sewed together into one continuous piece or web, and this web, spread out to the full width of the goods or gathered into a rope, as the nature of the treatment may determine, is drawn from one process to another until the treatment is completed. It first usually passes close to a red-hot plate or cylinder in order to singe loose fiber and lint. After singeing it may be given a preliminary washing in water in order to soften the impurities, which are chiefly sizing materials, such as starch or china clay, but it is more frequently subjected at once to the kier boil.

For this process the cloth is packed in large iron vats or kiers and boiled for several hours with caustic soda or with lime and steam. The kiers have false bottoms, and circulating devices arranged so that the boiling liquor flows on the goods and then passes downward

through them, softening and removing the impurities. For the finer grades the caustic boil is used, consisting of 40 to 50 pounds of caustic soda and 1,000 gallons of water with each ton of material. A large amount of the organic matter is dissolved by this liquor, which becomes very dark colored and loses part of its causticity. For the coarser materials the lime boil is used. It consists of 50 to 60 pounds of lime, as milk of lime, with 1,000 gallons of water for each ton of goods treated. Much of the organic matter forms insoluble compounds with the lime in this boil and remains on the cloth, but the greater part passes out with the waste liquor. After the boil has been completed the liquor is drawn into the sewer and the goods are drained.

When the goods are removed from the kier, they carry with them more than one-third of the kier-boil liquor, together with insoluble matters that have been loosened from or deposited on the fabric. This matter is removed by washing machines, in which the rope of cloth passes over rollers immersed in a stream of running water. As 8,000 to 10,000 gallons of water are used in this process for each ton of material, the waste water is very dilute, containing only 4 to 5 per cent as much foreign matter as the kier-boil liquor, though its portion of suspended matter is relatively greater. The amount of impurities removed from the cloth in the kier boils and in the subsequent washing is generally from 8 to 15 per cent of the weight of the cloth.

After the cloth has been passed through the washing machines the bleaching is continued. The fabric is passed through chloride of lime solution, is rinsed, and is allowed to stand for a few hours in stone or masonry vats. Souring by weak sulphuric or hydrochloric acid, rinsing, treatment in baths of sulphurous acid and soda ash follow in succession. The chemic, sour, and soda-ash solutions are used over and over. The rinse waters are run to waste, and they carry with them small amounts of cloth impurities and mineral matter from the baths. The quantity of water used in these processes is large, and the waste waters are in consequence very dilute. They were not included in the investigations made by the writers at Saylesville.

A piece of cloth in some of the later bleaching or finishing processes is often found to be stained or dirty. If it does not seem necessary to subject this a second time to the entire bleaching procedure, it may be washed in "dolly" washers preparatory to finishing, but only a small percentage of the goods in the bleachery reaches these washers, in which the cleansing process consists merely in soaping the goods and washing them in water. About 350 gallons of water and 1½ pounds of soap are used for each ton of material bleached. The waste waters are somewhat soapy in appearance and they contain but little refuse matter.

The chemic solution is prepared by agitating commercial chloride of lime with water. The lime compound is not chemically pure, and a semiliquid sludge, which settles out, is discharged as a waste product. It amounts to about 5½ gallons (45 to 50 pounds) per ton of material bleached. It is similar to milk of lime in appearance and contains chiefly calcium compounds. A partial analysis of it gave the following results: Total solids, 18.6 per cent; loss on ignition, 0.34 per cent; insoluble in hydrochloric acid, 0.89 per cent; reaction, alkaline.

The analyses of wastes from the Saylesville bleachery in Table 25 show the great concentration of the kier liquors and the comparative weakness of the other waste waters. The same fact is brought out even more clearly by the estimates in Table 26.

TABLE 25.—*Character of liquors at Saylesville, R. I.*[a]

[Milligrams per liter.]

	Waste from the lime boil.	Waste from the caustic soda boil.	Rinse water from the lime boil.	Rinse water from the caustic soda boil.	Effluent from the dolly washers.
Color	Orange.	Reddish brown.	Gray.	Light orange.	Soapy.
Odor	Lime.	Alkali.	Lime.	Alkali.	Soapy.
Turbidity	120	600	260	220	350
Sediment	Heavy.	Slight.	Heavy.	Considerable.	Heavy.
Oxygen consumed	5,200	5,000	154	168	136
Nitrogen as free ammonia	5	5	0.3	0.2	0.03
Organic nitrogen	190	233	6.4	8.0	1.15
Alkalinity as $CaCO_3$	1,840	3,600	84	180	52
Fats	848	974	20	130	84
Total solids	17,230	18,280	808	850	848
Loss on ignition	11,970	10,860	532	520	612

[a] Analyses by Pratt and Stabler.

TABLE 26.—*Quantity of waste liquors and solids in same, Saylesville, R. I.*

Waste.	Gallons per diem.	Tons per diem.		
		Total.	Inorganic.	Organic.
Caustic and lime boils	60,000	6.70	2.30	4.40
Rinse waters from same	825,000	3.40	1.20	2.20
Dolly washer wastes	24,000	.08	.02	.06
Other waste liquors	5,091,000	2.32	2.23	.09
	6,000,000	12.50	5.75	6.75

PURIFICATION OF WASTE BLEACHING LIQUORS.

So far as known to the authors, the purification of the concentrated liquors from the kiers has not heretofore been attempted, though treatment of the combined waste liquors of bleacheries has been effected with varying degrees of success.

Purification in England.—The bleaching processes in England, according to Naylor,[a] are somewhat different from those herein outlined, and the liquors, though similar in quality of impurities, are widely different in concentration from those which were studied at Saylesville. The waste liquors in England contain principally organic matter, such as resins, fats, starches, waxes, and soaps, both in suspension and in solution, lime and calcium salts in solution, china clay in suspension, and soluble salts of sodium and potassium.

The sodium and potassium salts, principally chlorides, are not at present susceptible to practical precipitation nor to any other mode of elimination, except the commercially impossible method of recovery by evaporation of the water. Most of the lime is precipitated as sulphate by the sulphuric acid of the sour liquors, if the wastes are allowed to mix and settle. The precipitate, however, is usually not sufficiently dense, and carries with it the buoyant soaps, starches, or fats, the result being a turbid liquor resembling an emulsion, though eventually clarification nearly always takes place. Such purification is too tedious and requires far too much settling space. Up to the present time the most successful method of clarification is by means of precipitation tanks, successful installations of which are described by Naylor. At Leyland, Lancashire, 500,000 gallons daily of mixed liquors from dyeing and bleaching cotton are treated by precipitation with lime and alumina ferric. The supernatant liquor is usually discharged into the river, but it is sometimes filtered through 5 feet of sand and furnace clinkers, after which it is again used in the bleachery. The amount of waste water is estimated at 50,000 gallons per ton of cloth. The following figures from Naylor's account show the concentration of the liquor that is treated and the purification that takes place.

TABLE 27.—*Purification of bleaching liquors at Leyland, Lancashire, England.*

Source.	Solids in parts per million.		Per cent removal.		
	Total.	Volatile.	Total.	Volatile.	Remarks.
Raw liquor	1,660	680			Highly discolored.
Supernatant liquor	1,320	400	20	41	Clear.
Effluent from filter	660	100	60	85	Clear and sparkling.

Precipitation appears to be satisfactory only as a preliminary process, the greater part of the purification being accomplished by sand filtration. The sludge removed by precipitation contains about 95 per cent water and is, so far as known, valueless. Accord-

[a] Naylor, W., Trades waste; its treatment and utilization, 1902, pp. 164–180.

ing to the foregoing figures, the sludge amounts to about 2.68 pounds of dry material or 53.6 pounds of wet material per 1,000 gallons; 0.93 pound of alumina ferric per 1,000 gallons is used; the amount of lime used is not stated. Although no estimates of cost are given, a plant of this character would cost about $15,000 in the United States, excluding cost of land; and the total annual cost of operation and maintenance would amount to $6,000, or about 4 cents per 1,000 gallons.

Naylor states that a similar purification plant at the works of Grafton & Co. is unable to accomplish results as satisfactory as those at Leyland. The admixture of soapy liquors at this plant renders the deposition of a precipitate difficult, and it was concluded that satisfactory treatment by precipitation could not be accomplished, unless the soapy liquors were segregated and treated with very large quantities of precipitants. Naylor states also that application of bleachery wastes to land is unsatisfactory because they tend to undergo acid fermentation, and that artificial filters soon became choked and failed to work. He recommends bacterial treatment in septic tanks, followed by filtration through sprinkling filters. Such installation proved successful in treating mixed bleaching and dyeing liquors at the works of Peel, Tootal & Co., after precipitation tanks and ordinary continuous-flow filters had been found to be unsatisfactory. The septic tank of this company is of sufficient size to provide three days' storage and it was seeded with sewage sludge. Putrefaction is maintained by allowing the sewage of employees to enter the waste waters and by occasional additions of sewage sludge. The filter material is cinders graded from not more than 2½ inches diameter at the bottom to not less than one-fourth inch diameter at the surface. A similar plant was installed at Leyland after a septic tank and contact filters had proved to be unsatisfactory. Septic tanks and filters can not be maintained unless the chloride of lime solution is separated from the wastes.

Purification in Massachusetts.—Experiments in the United States on the purification of bleachery wastes have been reported by the Massachusetts state board of health.[a] The liquor treated was much more dilute than the kier liquors used in the experiments by the authors. It was "a mixture of the stronger" bleachery waste waters. The fairly clear supernatant liquor, which was left after the soap in the mixture had been precipitated, was applied at the rate of 50,000 gallons per acre per day to a filter of 3 feet of sand having an effective size of 0.25 millimeter. Table 28 shows the extent of the reduction in solids accomplished by sedimentation and filtration.

[a] Thirty-eighth Ann. Rept. Massachusetts State Board Health, 1906, p. 300.

TABLE 28.—*Purification of stronger bleaching liquors in Massachusetts.*

Source	Solids in milligrams per liter.		Per cent removal.		Remarks.
	Total.	Volatile.	Total.	Volatile.	
Raw liquor	2,926	696			
Supernatant liquor	2,494	548	15	21	Fairly clear.
Effluent from filter	1,821	148	38	79	Clear, colorless, nonputrescible.

A removal of about 90 per cent of the organic matter was effected, as measured by determinations of both albuminoid ammonia and oxygen consumed. The raw liquor contains much more mineral matter than that treated by precipitation and filtration at the plant at Leyland, England, but the content of organic matter is practically the same. Precipitation appears to give more satisfactory results than sedimentation, though the filtration reported by Naylor[a] is less efficient, as may be expected from comparison of the filtering media that were used.

Sedimentation, precipitation, and septic treatment of bleachery wastes appear to be satisfactory only as preliminary processes; and the degree of purification increases in the order in which the processes are named. The best secondary treatment seems to be bacterial filtration, sprinkling filters and sand filters having proved to be satisfactory and contact filters unsatisfactory.

TREATMENT OF LIME-BOIL AND CAUSTIC-BOIL LIQUORS.

LABORATORY EXPERIMENTS.

The authors' experiments were confined to the most concentrated of all bleachery wastes, the lime-boil and the caustic-boil liquors. Sulphuric acid or the sludge from chloride of lime solution produces a heavy precipitate when mixed with the kier liquors, and precipitation with these substances was tried in the laboratory. The precipitate with acid, although apparently of great bulk and composed almost entirely of organic matter, contains so small a percentage of the impurities that this method of treatment was rejected. The best result obtained was a 17 per cent removal of volatile solids from the caustic-boil liquor with acid in the proportion of 52 pounds of sulphuric acid to 1,000 gallons of waste.

The use of lime sludge on the caustic-boil liquor also failed to give satisfactory results, but the sludge is an effective precipitant for the lime-boil liquor. The mixing of 3.2 volumes of sludge with 100 volumes of liquor gave a 32 per cent reduction in volatile solids, but smaller amounts of sludge gave less efficient purification. The use of

[a] Naylor, W., Trades waste; its treatment and utilization, 1902, pp. 164-180.

such sludge on lime-boil liquors to aid other coagulants in purification by precipitation would probably be economical. The amount of sludge produced at Saylesville is sufficient to precipitate only about a third of the lime-boil liquors. If subsequent treatment of all the liquor by bacterial methods is contemplated, the use of lime sludge is undesirable because of the inhibiting effect of its hypochlorites on bacterial growth.

EXPERIMENTS AT SAYLESVILLE, R. I.

Description of purification plant.—A small plant, consisting of storage tank, septic tank, and filters for the treatment of mixed lime-boil and caustic-boil liquors was installed at the Saylesville bleachery. The storage tank, an old boiler shell of 750-gallon capacity, was so placed that 460 gallons of liquid could be discharged from it into the septic tank by gravity, and a drain plug was provided to facilitate the discharge of all the remaining liquor if desirable. The septic tank, an open iron vat about 8 feet long with a capacity of 350 gallons under the conditions of operation, had sloping sides and a rounded bottom. It varied in width from 2½ feet at the top to 1½ feet near the bottom, and it had a maximum depth of about 2½ feet. An inflow pipe connected with the storage tank and regulated by a valve discharged downward at mid depth of the septic tank. The effluent was taken from mid depth by a similar pipe, and no baffles were used to direct the flow. A drainpipe provided for sludge removal and for cleaning.

Each of the 7 filters was an open galvanized-iron cylinder 6 feet deep and 20 inches in diameter, with a filtering area of 2.18 square feet, or one twenty-thousandth of an acre. The filters were exposed to all weather conditions. The filtering media were found on the bleaching premises. An immense bank of good quality filter sand was available, which without treatment had the following characteristics: Effective size, 0.27 millimeter; uniformity coefficient, 4.8; smaller than 0.10 millimeter, 1 per cent; lime by hydrochloric acid test, none. Coke, the only other filtering medium that was used, was obtained from a water-gas plant on the premises. It was broken in order to obtain pieces varying from one-half inch to 2½ inches in diameter.

Operation of storage tank.—A pipe was laid from the storage tank to the kier house and branches were connected to the kiers used for the lime boil and the caustic boil. A steam jet forced the liquors from the kiers to the storage tank every morning when the kiers were emptied. Usually the liquors from both lime and caustic boils were available, in which case the mixed liquors were used to fill the tank, but sometimes only one class of kier liquor could be obtained and occasionally no liquor could be procured. Generally, however,

the storage tank was filled five or six times a week with scalding-hot kier liquors. The valve on the pipe connecting the storage and the septic tank was so regulated that 460 gallons of liquor were discharged from the storage tank in about fifteen hours. On July 16 there was a slight evidence of septic action in the storage tank, which was confirmed by the bacterial counts on samples collected July 12 and July 23; accordingly the tank was flushed weekly after July. Table 29 gives the results of testing 13 samples of the untreated liquor which was used in the work on experimental purification. The examinations cover a period of about four months and the samples were dipped from the storage tank. These analyses represent a very strong alkaline waste.

TABLE 29.—*Character of untreated waste liquor at Saylesville, R. I.*[a]

[Milligrams per liter.]

Date.	Residue on evaporation.			Nitrogen as free ammonia.	Organic nitrogen.	Oxygen consumed.	Number of bacteria per cubic centimeter.
	Total.	Loss on ignition.	Fixed.				
1907.							
June 7	17,412	11,962	5,450	2.5	191	5,200	550
June 14	18,086	10,964	7,122	4.0	222	5,160	1,000
June 21	20,544	12,952	7,592	4.0	226	5,280	1,000
June 26	17,240	11,412	5,828	3.0	228	5,220	10
July 12	16,676	9,264	7,412	1.5	229	3,540	[b] 1,900,000
July 23	14,980	8,652	6,328	1.5	196	3,260	[b] 11,800,000
July 31				5.5	210	5,080	425
August 8	18,576	12,380	6,196	3.0	201	3,760	90,000
August 20				5.7	210	4,960	10,000
August 28				9.8	160	5,340	Low.
September 11				6.5—	203	5,060	600
September 18				6.6	148	3,740	1,500
September 27				4.0	125	3,780	400
Average				4.4	196	4,570	

[a] Analyses by G. H. Pratt. [b] Some evidence of septic action in storage tank, July 16, 1907.

Operation of septic tank.—The septic tank was dosed five or six times a week with 460 gallons of waste liquor, and, since the capacity of the tank was only 350 gallons, a complete change of its contents was effected each time. The septic period, with regular dosing, varied from twelve to twenty-one hours, with a probable average of sixteen hours. The tank was filled on May 22, 1907, and a keg full of sewage sludge was distributed through the contents to start bacterial action. Active gasifaction accompanied by a characteristic pigpen odor was apparent in a few days. On May 30 regular dosing was begun. On August 7 the septic tank contained a little over a foot of heavy black sludge, which was beginning to escape with the effluent from the tank. This deposit was therefore drawn off, leaving only about 1 to 2 inches in the bottom, and the operation of the tank was resumed. The plant was dismantled on November 26 on account of the piping that would have been exposed to very severe weather.

The results in Table 30 were obtained on 13 samples of liquor taken as it flowed from the septic tank to the filters; they cover a period of about four months.

TABLE 30.—*Character of septic tank effluent, Saylesville, R. I.*[a]

[Milligrams per liter.]

Date.	Residue on evaporation.			Nitrogen as free ammonia.	Organic nitrogen.	Oxygen consumed.	Number of bacteria per cubic centimeter.
	Total.	Loss on ignition.	Fixed.				
1907.							
June 7	13,776	9,182	4,594	5.0—	181	4,040	14,000,000
June 14	15,606	10,264	5,342	6.5—	231	5,320	21,000,000
June 21	14,692	8,132	6,560	1.5—	176	3,620	11,500,000
June 26	15,780	8,964	6,816	1.5—	196	2,660	12,000,000
July 12	15,160	7,312	7,848	2.5—	229	2,320	10,710,000
July 23	14,020	7,532	6,488	4.0	203	2,560	21,200,000
August 8	12,800	7,200	5,600	14.8	198	2,820	3,600,000
August 20				14.8	136	3,880	1,000,000
August 28				18.0	155	3,880	70,000
September 11				7.5—	232	4,000	190,000
September 18				15.6	158	2,740	120,000
September 27				5.0	146	3,020	160,000
October 11				7.4	139	2,440	143,000
Average				8.0	183	3,330	

[a] Analyses by G. H. Pratt.

Operation of filters.—The effluent from the septic tank was applied to all the filters except No. 6, which was dosed for a short time with liquor from the storage tank, but later with the septic-tank effluent. Filters Nos. 1 and 2 each had 4½ feet of coke for the filtering medium; they were operated first as continuous trickling filters and later as intermittent trickling filters dosed by siphons. Filters Nos. 3 to 7, inclusive, were operated as sand filters, each containing as the filtering medium 4½ feet of sand underlain by 1 foot of coke; the filters were dosed at different intervals and the rates of filtration were varied. Determinations of albuminoid ammonia in samples of sand collected from these five filters on November 26 are given in Table 38. Analyses by G. H. Pratt of samples of the effluents from all the filters are detailed in Tables 31 to 37, inclusive.

TABLE 31.—*Character of effluent from filter No. 1, Saylesville, R. I.*

[Milligrams per liter.]

Date.	Turbidity.	Sediment.	Color.	Odor.	Residue on evaporation.			Nitrogen as free ammonia.	Organic nitrogen.	Oxygen consumed.	Number of bacteria per cubic centimeter.
					Total.	Loss on ignition.	Fixed.				
1907.											
June 7	300	Very heavy	Dark beer	Burnt sugar and alkali	11,230	6,956	4,274	4.0—	85	3,000	5,250,000
June 14	380	Heavy	Dark brown	Decidedly disagreeable and musty	12,742	8,162	4,580	5.5—	131	3,140	11,500,000
June 21	600	Considerable	Black coffee	Hogpen and moldy	10,580	6,592	3,988	3.5—	128	2,250	8,500,000
June 26	1,200	do	do	do	9,244	4,560	4,684	8.0—	147	1,520	1,200,000

TABLE 32.—*Character of effluent from filter No. 2, Saylesville, R. I.*

[Milligrams per liter.]

Date.	Turbidity.	Sediment.	Color.	Odor.	Residue on evaporation.			Nitrogen as free ammonia.	Organic nitrogen.	Oxygen consumed.	Number of bacteria per cubic centimeter.
					Total.	Loss on ignition.	Fixed.				
1907.											
June 7	[a] 500	Very heavy	Very dark beer	Burnt sugar and alkali	12,146	7,638	4,508	5.5—	120	3,600	3,720,000
June 14	[a] 800	do	Light muddy brown.	Decidedly disagreeable and moldy	13,266	7,874	5,392	4.5—	201	4,340	35,000,000
June 21	[a] 1,000	do	Muddy coffee	Hogpen	15,612	8,728	6,884	3.5—	196	3,840	15,700,000
June 26	[a] 800	Considerable	Coffee	do	15,620	8,364	7,256	2.5—	191	2,580	1,000,000

[a] Very great.

TABLE 33.—*Character of effluent from filter No. 3, Saylesville, R. I.*

[Milligrams per liter.]

Date.	Turbidity.	Sediment.	Color.	Odor.	Residue on evaporation.			Nitrogen as free ammonia.	Organic nitrogen.	Nitrogen as—		Oxygen consumed.	Number of bacteria per cubic centimeter.
					Total.	Loss on ignition.	Fixed.			Nitrates.	Nitrites.		
1907.													
June 7	[a]220	Considerable	Whitish	Distinctly moldy	2,472	772	1,700	3.0—	5.0	Trace (?)	0.002	145	Low.
June 14	[b]350	Slight	Pale straw, darker on standing.	do	3,484	1,040	2,444	.0—	7.0	Trace.	Trace.	288	2,500,000
June 21	[b]180	Very slight	Lemon	Decidedly moldy	6,408	3,056	3,352	1.5—	34.1	Trace.	Trace (?)	640	1,500,000
June 26	[c]120	Slight	Lemon juice	do	7,040	3,304	3,736	1.5—	28.0	0.00 (?)	.000	538	40,500
July 12	([c])	do	Weak tea	Distinctly moldy	8,656	3,528	5,128	12.5—	42.0 (?)	.00 (?)	.000 (?)	406	90,000
July 23	([c])	do	Muddy beer	Distinctly unpleasant and moldy.	9,492	3,504	5,988	32.8	76.4	Trace (?)	.000	562	30,000
July 31	([c])	Very slight	Dark tea	Faintly unpleasant				33.6	82.8			664	1,300,000
August 8	([b])	None	Muddy beer	do				44.3	73.0	Trace (?)	.000	615	270,000
August 20	([c])	Considerable	Muddy brown	do				48.8	48.8	.00 (?)	.000	460	160,000
August 28	([c])	Very slight	Muddy beer	Distinctly unpleasant				42.6	38.1		.000	400	50,000
September 11	([c])	do	Yellowish	Faintly unpleasant				22.1	16.0	.00 (?)	.000	148	65,000
September 18	([c])	Slight	Yellowish brown	Distinct of celery				23.8	18.0	.00 (?)	.000	150	11,000
September 27	([d])	do	do	Very faintly unpleasant.				38.1	38.1	.00 (?)	.000 (?)	246	13,000
October 11	([a])	Very slight	Reddish brown	do				14.8	25.8	.00 (?)	.020 (?)	180	11,200
October 23	([d])	None	Dark ale	Faintly unpleasant				6.2	41.0	.00 (?)	.050 (?)	530	216,000
November 1	([e])	Very slight	Dark beer	Distinctly sweetish				11.1	84.5	Trace (?)	.000	1,200	
November 13	([c])	Slight	Brown	do				10.7	45.1	Trace (?)	.000	510	28,200

[a] Very slight. [b] Great. [c] Decided. [d] Slight. [e] Very decided.

TABLE 34.—*Character of effluent from filter No. 4, Saylesville, R. I.*

[Milligrams per liter.]

Date.	Turbidity.	Sediment.	Color.	Odor.	Residue on evaporation.			Nitrogen as free ammonia.	Organic nitrogen.	Nitrogen as—		Oxygen consumed.	Number of bacteria per cubic centimeter.
					Total.	Loss on ignition.	Fixed.			Nitrates.	Nitrites.		
1907.													
June 7	[a]170	Considerable	Dark straw	Decidedly moldy	5,546	2,746	2,800	3.0—	34	0.00	0.000	1,270	8,750,000
June 14	[a]105	Slight	Pale straw	do	7,040	3,520	3,520	1.0—	37	.00	.000	1,290	8,500,000
June 21	[a]140	do	Weak tea	do	9,948	4,940	5,008	2.5—	65.2	.00	.000	1,400	800,000
June 26	[b]120	do	do	do	10,828	5,460	5,368	9.5—	74.0 (?)	.00 (?)	.000	1,160	40,000
July 12	[b]	Very slight	Muddy dark beer	Decidedly moldy and alkali.	11,136	4,600	6,536	36.0—	91.0 (?)	.00 (?)	.000 (?)	710	85,000
July 23	[b]	Slight	Muddy beer	Distinctly unpleasant and moldy.	11,104	4,320	6,784	55.8	98.4	Trace (?)	.000	805	80,000
July 31	[c]	Very slight	Dark tea	do				53.3	94.8			700	50,000
August 8	[d]	None	do	Faintly unpleasant				55.0	86.9	Trace (?)	.000	675	60,000
August 20	[b]	Very slight	Muddy ale	do				46.7	63.6	.00 (?)	.000	625	40,000
August 28	[d]	do	Dark beer	Distinctly unpleasant				48.4	54.1		.000	555	10,000
September 11	[a]	Slight	Brown	Faintly unpleasant				23.8	28.3	(?)	Trace.	232	17,000
September 18	[b]	Very slight	Yellowish brown	do				28.3	23.8	.00 (?)	.000	276	2,000
September 27	[b]	Slight	Turbid brown	Barnyard				50.4	56.6	.00 (?)	.000	362	500
October 11	[c]	Very slight	Reddish brown	Faintly moldy				30.8	44.7	.00 (?)	.000	320	8,400
October 23	[a]	Considerable	Turbid brown	Faintly hogpen				30.3	45.5	.00 (?)	.100 (?)	572	18,400
November 1	[f]	Slight	Turbid dark beer	Distinctly sweetish				23.0	89.4	Trace (?)	Trace (?)	1,100	
November 13	[b]	do	Dark beer	Distinctly sweetish and unpleasant.				17.6	52.9	Trace (?)	.100 (?)	790	9,000

[a] Great. [b] Decided. [c] Very slight. [d] Slight. [e] Very great. [f] Very decided.

TABLE 35.—*Character of effluent from filter No. 5, Saylesville, R. I.*

[Milligrams per liter.]

Date.	Turbidity.	Sediment.	Color.	Odor.	Residue on evaporation.			Nitrogen as free ammonia.	Organic nitrogen.	Nitrogen as—		Oxygen consumed.	Number of bacteria per cubic centimeter.
					Total.	Loss on ignition.	Fixed.			Nitrates.	Nitrites.		
1907.													
June 7	*a* 220	Considerable	Dark straw	Decidedly moldy	7,032	3,700	3,332	2.5—	52.5	0.00	0.000	1,580	12,000,000
June 14	*a* 150	Slight	do	do	11,090	5,900	5,190	1.0—	81.0	.00	.000	1,800	5,200,000
June 21	*a* 100	Very slight	Weak tea	do	13,052	6,800	6,252	5.5—	88.8	.00	.000	1,690	900,000
June 26	*b* 100	Slight	Tea	do	13,136	6,700	6,436	17.0—	99.0 (?)	.00 (?)	.000	1,450	40,000
July 12	(*b*)	Very slight	Dark beer	Decidedly moldy and alkali.	12,356	5,512	6,844	46.5—	100.5 (?)	.00 (?)	.000 (?)	850	60,000
July 23	(*b*)	do	Very dark ale	Decidedly unpleasant and moldy.	12,312	5,040	7,272	65.6	109.0	Trace (?)	.000	1,060	50,000
July 31	(*c*)	Slight	Turbid light beer	Decidedly moldy				46.3	80.8			650	380,000
August 8	(*c*)	Very slight	Dark beer	Distinctly moldy				47.6	97.2	Trace (?)	.000	760	100,000
August 20	(*b*)	do	Muddy ale	Faintly unpleasant				41.8	76.3	.00 (?)	.000	665	110,000
August 28	(*a*)	Considerable	Brownish black	Hogpen				44.3	85.3		.000	730	5,000
September 11	(*a*)	do	Muddy brown	do				38.4	59.0	(?)	.000	520	24,000
September 18	(*a*)	Slight	Dark muddy brown.	Barnyard				44.3	58.6	.00 (?)	.000	450	330,000
September 27	(*a*)	do	Dark brown	do				46.3	60.7	.00 (?)	.000	358	25,000
October 11	(*d*)	do	Reddish brown	Hogpen				22.6	56.6	.00 (?)	.060 (?)	310	12,800
October 23	(*a*)	Considerable	Turbid brown	do				15.6	52.1	.00 (?)	.050 (?)	382	77,000
November 1	(*a*)	do	Chocolate	Distinctly sweetish				12.7	76.7	Trace (?)	Trace (?)	588	
November 13	(*a*)	Very slight	Turbid dark beer	Distinctly sweetish and unpleasant.				9.0	40.2	Trace (?)	Trace (?)	510	6,800

a Great. *b* Decided. *c* Slight. *d* Very great.

TABLE 36.—*Character of effluent from filter No. 6, Saylesville, R. I.*

[Milligrams per liter.]

Date.	Turbidity.	Sediment.	Color.	Odor.	Residue on evaporation.			Nitrogen as free ammonia.	Organic nitrogen.	Nitrogen as—		Oxygen consumed.	Number of bacteria per cubic centimeter.
					Total.	Loss on ignition.	Fixed.			Nitrates.	Nitrites.		
1907.													
July 23	None	None	Strong clear tea	Sweetish of sugar	10,530	4,400	6,130	3.0—	28.7	Trace (?)	0.600	1,250	20,000
July 31	do	Very slight	Dark wine	Distinctly sweetish and moldy.				[a] 4.5	57.4			940	
August 8	Very slight	do	Dark tea	Distinctly unpleasant				4.5	64.4	Trace (?)	.000	640	20,000
August 20	None	Considerable	Dark vinegar	do				16.0	54.1	0.00 (?)	.000	655	80,000
August 28	Very great	do	Muddy coffee	Distinctly moldy				43.1	46.3		.000	490	10,000
September 11	do	Heavy red	Reddish brown	Distinctly sweetish and earthy.				17.2	38.5	(?)	Trace.	390	32,000
September 18	Very great (red).	do	Very turbid red brown.	Distinctly sweetish				16.4	19.2	.00 (?)	Trace.	285	3,500
September 27	Very great	do	Red brown	Sweetish and earthy				27.1	46.3	Trace (?)	Trace (?)	380	200
October 11	do	do	Reddish brown	do				26.7	37.3	.00 (?)	Trace (?)	280	5,400
October 23	do	do	do	do				20.5	54.5	.00 (?)	.050 (?)	390	8,400
November 1	do	do	Brown	Earthy and sweetish				13.5	60.3	Trace (?)	Trace (?)	680	
November 13	Very slight	Slight	Dark porter	Distinctly sweetish				10.3	57.0	Trace (?)	Trace (?)	810	11,800

[a] High (?).

TABLE 37.—*Character of effluent from filter No. 7, Saylesville, R. I.*

[Milligrams per liter.]

Date.	Turbidity.	Sediment.	Color.	Odor.	Residue on evaporation.			Nitrogen as free ammonia.	Organic nitrogen.	Nitrogen as—		Oxygen consumed.	Number of bacteria per cubic centimeter.
					Total.	Loss on ignition.	Fixed.			Nitrates.	Nitrites.		
1907.													
July 23	Great	Considerable (red).	Orange brown	Sweetish of sugar	8,576	3,072	5,504	4.9	20.0	Trace (?)	0.200	374	20,000
July 31	Slight	Very slight	Dark ale	Distinctly sweetish and moldy.				[a]4.5	102.0			1,420	600,000
August 8	Great	do	Very dark porter	Distinctly unpleasant				7.5	117.8		.000	1,620	2,600,000
August 20	Decided	Considerable	Very dark brown	Very faintly unpleasant.				17.2	56.6	0.00 (?)	.000	850	120,000
August 28	Slight	Very slight	Dark beer	Distinctly unpleasant				38.5	41.0		.000	490	50,000
September 11	Decided	Slight	Brownish yellow	Faintly unpleasant				20.9	28.3	(?)	Trace.	186	4,000
September 18	do	do	Yellowish brown	do				23.3	23.3	.00 (?)	.000	234	6,500
September 27	Great	Considerable (red).	Reddish brown	do				35.3	50.0	Trace (?)	.000 (?)	380	11,000
October 11	Very great	do	do	Very faintly unpleasant.				20.5	41.8	.00 (?)	.100 (?)	300	10,600
October 23	Great	Heavy (red)	do	Faintly unpleasant				17.6	44.3	.00 (?)	.100 (?)	320	15,000
November 1	Very decided	None	Dark beer	Very faintly unpleasant.				12.3	61.1	Trace (?)	.000 (?)	344	
November 13	Very great	Heavy (red)	Light coffee	Distinctly sweetish				9.0	45.5	Trace (?)	.160 (?)	390	4,400

[a] High (?).

TABLE 38.—*Albuminoid ammonia in sand from filters, Saylesville, R. I.*[a]

[Milligrams per liter.]

Source of sand.	Filter No.				
	3.	4.	5.	6.	7.
Surface	586	558	129	248	555
6 inches down	232	246	155	210	161
2 feet down	75	56	[b]65	101	121
4 feet down	45	41	56	83	67

[a] Analyses by G. H. Pratt. [b] Sample taken a little more than 2 feet down.

Filter No. 1 was operated as a continuous trickling filter four days a week from May 30 to June 7, but the distribution of the liquor over the surface was poor. The filter was dosed at the rate of 70,000 gallons per acre, a net rate of 40,000 gallons per acre per day. It was operated as an intermittent trickling filter dosed by a siphon with fair distribution over the surface from June 8 to June 26, the dose being applied five days a week at the rate of 70,000 gallons per acre, a net rate of 50,000 gallons per acre per day.

Filter No. 2 was operated as a continuous trickling filter four days a week from May 30 to June 7. The distribution of liquor over the surface was poor. The filter was dosed at the rate of 120,000 gallons per acre, a net rate of 70,000 gallons per acre per day. It was operated as an intermittent trickling filter dosed by a siphon with fair distribution over the surface from June 8 to June 14, during which period the dose was applied five days a week at the rate of 120,000 gallons per acre, a net rate of 85,000 gallons per acre per day. It was operated as a contact filter from June 15 to June 26, with one treatment a day six days in a week. It was filled in an hour, and was emptied in one-half hour, the contact lasting eight hours. It was dosed at the rate of 650,000 gallons per acre per day, a net rate of 560,000 gallons per acre per day.

Filter No. 3 was dosed once daily six times a week from May 30 to June 14, at the rate of 20,000 gallons per acre, a net rate of 17,000 gallons per acre per day. It was dosed once daily three times a week from June 15 to June 26, at the rate of 40,000 gallons per acre, a net rate of 17,000 gallons per acre per day; once daily six times a week from June 27 to October 15, at the rate of 20,000 gallons per acre, a net rate of 17,000 gallons per acre per day; and once daily six times a week from October 16 to November 26, at the rate of 40,000 gallons per acre, a net rate of 34,000 gallons per acre per day. On September 11 the surface of the sand was leveled on account of a slight depression in the middle. On October 11 the sand was apparently in as good condition as when operation of the filter began. No clogging and only slight discoloration of the surface was evident. On

November 26 the sand in the center for about 2½ feet down was considerably darker in color than that on the sides.

Filter No. 4 was dosed once daily six times a week from May 30 to June 14, at the rate of 40,000 gallons per acre, a net rate of 34,000 gallons per acre per day, and once daily three times a week from June 15 to June 26, at the rate of 60,000 gallons per acre, a net rate of 26,000 gallons per acre per day.

During the rest of the time that it was operated, except the period from September 27 to October 7, the filter was dosed once daily at the rate of 30,000 gallons per acre, a net rate of 26,000 gallons per acre per day. On September 11 the surface was leveled on account of a slight depression in the sand. On September 27 the surface of the sand was black and the filter had hardly become dry from the dose of the day before. Wet weather prevailed at that time, and the dosing was delayed until the sand had become dry. By October 11 the condition of the surface had become much improved and the filter was apparently disposing of the dose satisfactorily, but there was some question as to whether the filter would remain efficient without being scraped. During the first part of November the dose just disappeared from day to day, and on November 13 a small amount of liquor was still on the surface of the sand, which was black with a slimy deposit. On November 26 the surface of the sand was dark-colored for about 8 inches down from the surface, but it was fairly clean below that point.

Filter No. 5 was dosed once daily six times a week from May 30 to June 14 with a dose equivalent to 80,000 gallons per acre, a net rate of 69,000 gallons per acre per day. From June 15 to June 26 it was dosed once daily three times a week, at a rate of 80,000 gallons per acre, a net rate of 34,000 gallons per acre per day. From June 27 to July 24 the dose was equivalent to 40,000 gallons per acre six times a week, a net rate of 34,000 gallons per acre per day. From July 25 to August 8 the dose was equivalent to 80,000 gallons per acre six times a week, a net rate of 69,000 gallons per acre per day. From August 8 to September 1 the dose was applied three times a week at the rate of 80,000 gallons per acre, a net rate of 34,000 gallons per acre per day. From September 12 to November 26 the dose was at the rate of 60,000 gallons three times a week, a net rate of 26,000 gallons per acre per day. Surface clogging was apparent on July 31, and on August 5 about one-quarter inch of the surface sand was removed. During the latter part of August the filter was not disposing of the dose satisfactorily, and though it had not received a dose for ten days the filter was still wet on September 11. A considerable depth of very black sand with a slimy coating on top at that time necessitated removal of about 3 inches of sand near the perimeter and about 8 inches at the center, after which the filter was

leveled and resurfaced with 6 inches of new sand. By November 26 the sand had become nearly black for a depth of 8 inches, except at the center, where it was dark-colored for a depth of 2½ feet. Otherwise the filter was in good condition.

Filter No. 6 was dosed with the raw liquor twice a day six times a week from July 13 to August 21, with an amount equivalent to 10,000 gallons per acre, a net rate of 17,000 gallons per acre per day; and once daily six times a week from August 22 to September 27 and from October 7 to October 11, at the rate of 30,000 gallons per acre, a net rate of 26,000 gallons per acre per day. From October 12 to November 26 septic liquor was applied at the rate of 60,000 gallons per acre three times a week, a net rate of 26,000 gallons per acre per day. On September 11 a slimy deposit on the sand was found to retard the operation of the filter, but the film was not disturbed. On September 27 the deposit was found to be so much thicker that dosing was discontinued till October 7, when the surface had become thoroughly dry. On October 11 practically all the previous dose was still on the filter; after the surface seal had been broken in order to allow the liquid to drain into the filter, 3 inches of dark-colored, slimy sand was removed. The considerable amount of discolored sand that was left was mixed with a trowel, and 3 inches of new sand was put on the surface. Though septic liquor was applied instead of raw liquor after that experience, the rate of filtration had become materially decreased at the end of October and the sand did not become dry between doses. On November 13 the surface of the sand was discolored and slimy and filter was not dry. On November 26 the sand was very dark-colored at the surface, and nearly black between 6 and 12 inches in depth, but the rest of the sand was in good condition.

Filter No. 7 was dosed twice a day six times a week, from July 13 to August 21, at the rate of 10,000 gallons per acre, a net rate of 17,000 gallons per acre per day; and from August 22 throughout the operation of the filter it was dosed twice a week at the rate of 90,000 gallons per acre, a net rate of 26,000 gallons per acre per day. The surface of the filter received no attention except on September 11, when the sand was leveled on account of a depression in the middle. On November 26 the sand was in good condition and clean for about 2 feet below the surface, then for about 1 foot it was slightly discolored. Below that layer the sand was in good condition.

Results of experimental work.—Table 39 presents a summary of the analytical results of work at Saylesville, together with the percentage removals of organic matter effected by the different filters; the averages of the analyses of raw and septic liquor are used as the bases of the computations. The rates of filtration and some other essential data are also included.

TABLE 39.—*Summary of results of purification experiments, Saylesville, R. I.*

Source of sample; effluent from—	Number of samples analyzed.	Source of applied liquor.	Number of doses weekly.	Dose per acre.	Net rate per acre per day.	Organic nitrogen.	Nitrogen as free ammonia.	Organic nitrogen and free ammonia.	Oxygen consumed.	Percentage removal based on organic nitrogen.	Percentage removal based on organic nitrogen and nitrogen as free ammonia.	Percentage removal based on oxygen consumed.
				Gallons.	*Gallons.*	*Milligrams per liter.*	*Milligrams per liter.*	*Milligrams per liter.*	*Milligrams per liter.*			
Storage tank	13	Lime and caustic boils.				196	4	200	4,570			
Septic tank	13	Storage tank				183	8	191	3,330	7	5	27
Filter No. 1 [a]	3	Septic tank		70,000	50,000	135	6	141	2,300	26	26	31
Filter No. 2 [a]	1	do		120,000	85,000	201	5	206	4,340	[b] 10	[b] 8	[b] 30
Do. [c]	2	do		650,000	560,000	194	3	197	3,210	[b] 6	[b] 3	4
Filter No. 3 [d]	2	do	3	40,000	17,000	31	1	32	589	83	83	82
Do. [d]	12	do	6	20,000	17,000	39	26	65	355	79	66	89
Do. [d]	3	do	6	40,000	34,000	57	9	66	747	69	65	78
Filter No. 4 [d]	2	do	6	40,000	34,000	36	2	38	1,280	80	80	61
Do. [d]	2	do	3	60,000	26,000	70	6	76	1,310	62	60	61
Do. [d]	13	do	6	30,000	26,000	64	38	102	594	65	47	82
Filter No. 5 [d]	4	do	6	80,000	69,000	78	24	102	1,198	57	47	64
Do. [d]	4	do	3	80,000	34,000	87	27	114	1,134	52	40	67
Do. [d]	2	do	6	40,000	34,000	105	56	161	955	43	16	71
Do. [e]	6	do	3	60,000	26,000	58	25	83	433	68	57	87
Filter No. 6 [d]	4	Storage tank	12	10,000	17,000	51	7	58	871	74	71	81
Do. [d]	5	do	6	30,000	26,000	37	26	63	365	81	69	92
Do. [e]	3	Septic tank	3	60,000	26,000	57	15	72	627	69	62	81
Filter No. 7 [d]	4	do	12	10,000	17,000	74	9	83	1,066	60	57	68
Do. [d]	8	do	2	90,000	26,000	42	22	64	330	77	67	90

[a] Operated as a trickling coke filter.
[b] Increase.
[c] Operated as a contact coke filter.
[d] Operated as an intermittent sand filter.
[e] After resurfacing.

The unsatisfactory work done by filters Nos. 1 and 2, operating as trickling coke and as contact filters, warrants their exclusion from any further consideration; the best purification accomplished by filter No. 1, operated as a trickling filter at the low rate of 50,000 gallons per acre per day and dosed with septic liquor, showed the removal of only about 30 per cent of the organic matter. The work done by the intermittent sand filters showed variations which were dependent on the changes in the rates and on the general condition of the filters in respect to clogging. The following conclusions seem warranted, after a careful consideration of all phases of the question:

1. Filtration of the raw liquor from the storage tank gives good removal for a time, but the bed soon becomes clogged. The use of the septic tank is desirable, for it insures a better general condition of the filters although the quality of the effluent may be somewhat inferior.

2. The septic period used in this work—about sixteen hours—seems to be satisfactory. Occasional seeding of the tank with fresh sewage sludge would probably improve the action.

3. The use of rates exceeding 26,000 gallons per acre per day appears to reduce the efficiency of the filters and renders their effluents unsatisfactory. Clogging of the surface results in a comparatively short time.

4. It is better to apply the liquor to the filters in large doses with long intermediate intervals rather than in smaller doses more frequently. This is emphasized by the satisfactory work and condition of filter No. 7 during a four months' run. The occasional removal of a few inches of sand and resurfacing maintains a satisfactory condition of filter and effluent.

5. No oxidation to nitrites and nitrates can be expected in filtration of this waste at the rates used.

6. The liquor can be filtered after septic treatment with good results (80 to 85 per cent removal of organic matter), at rates approximating 25,000 gallons per acre per day by dosing the beds with 90,000 gallons twice a week. If the net rate of filtration is maintained at 20,000 gallons per acre per day, over 85 per cent removal of organic matter is effected.

ESTIMATES OF COST.

The approximate cost of a purification plant to treat lime-boil and caustic-boil liquors, and the cost of its maintenance, are shown in the following tables. The estimates apply to a plant including a storage or equalizing tank, a septic tank, and intermittent sand filters capable of treating 60,000 gallons a day. They are based on the costs of several sewage-treatment plants in New England.

TABLE 40.—*Estimates of cost of installing kier-boil liquor treatment plant.*

Rate of filtration in gallons per acre per day.	Filtration area.	Total cost.	Cost per 1,000 gallons of daily capacity.
	Acres.		
15,000	4.0	$20,000	$330
20,000	3.0	16,000	270
25,000	2.4	13,600	230
30,000	2.0	12,000	200

TABLE 41.—*Estimates of annual maintenance costs for kier-boil liquor treatment plant.*

Rate of filtration in gallons per acre per day	15,000	20,000	25,000	30,000
Interest on investment	$1,000	$800	$680	$600
Depreciation and repairs	$840	$820	$800	$780
Labor	$640	$480	$380	$320
	$2,480	$2,100	$1,860	$1,700
Cost per 1,000 gallons.....cents.	13.8	11.7	10.3	9.5

The foregoing estimates are believed to cover all usual cases and they can probably be reduced considerably for most installations.

SUMMARY.

Bleaching processes give rise to the discharge of great quantities of waste waters which are undesirable additions to streams.

The dilute mixed waste waters have been partly purified in practice in England and experimentally in Massachusetts. These installations indicate that sedimentation, precipitation, and septic treatment are satisfactory only as preliminary processes; that the degree of purification increases in the order in which the processes are named; and that the best secondary treatment is bacterial filtration, chlorine solutions being excluded. Sprinkling filters and sand filters have done satisfactory work, but contact filters have proved unsatisfactory.

The investigations of the authors show that 1 per cent of the entire volume of waste waters contains about 40 per cent of the mineral pollution and 65 per cent of the organic pollution from a bleachery. This small portion of the waste consists of the waste kier liquors produced by boiling the unbleached cloth with caustic soda or caustic lime. If the waters derived from rinsing the cloth after boiling are included, 15 per cent of the total volume of waste waters contains 61 per cent of the mineral and 98 per cent of the organic pollution from a bleachery.

Laboratory experiments indicate that neutralization of the concentrated kier liquors by acid produces a voluminous precipitate but results in little actual purification. The lime sludge from the chloride of lime solution tanks precipitates lime-boil liquors and removes about

one-third of the volatile solids, but such treatment is ineffective for caustic-boil liquors.

Field experiments on mixed kier liquors covering a period of six months indicate that septic treatment followed by sand filtration at rates not exceeding 30,000 gallons per acre per day removes 80 to 85 per cent of the organic matter that the waste contains. This is accompanied by still greater reduction of the polluting qualities and by marked improvement in the appearance of the liquor, probably rendering it incapable of causing a nuisance even in a small stream. The cost of this treatment amounts to about 10 cents per 1,000 gallons. In this way 50 to 55 per cent of the organic matter in all wastes from the bleachery may be removed at a cost of about 0.1 cent per 1,000 gallons.

THE MANUFACTURE OF OLEOMARGARINE, FERTILIZER, AND GLUE.

PROCESSES AND WASTE WATERS.

Oleomargarine and other butter substitutes are made from mixtures of animal and vegetable oils. Tallow and lard, the most important sources of stock, are contained in membranous cells which soon putrefy and cause the fats to become rancid. Therefore the stock is washed and cooled with water and rendered to obtain an oil free from animal tissue. The rendering is usually accomplished by digestion with steam under about 50 pounds pressure in iron containers. The cell walls are broken down and the melted fat, which rises above the tissue or "cracklings" and the water, can be decanted. The impure water is discharged as sewage or utilized for recovery of valuable materials.

A large amount of fertilizer is made from slaughterhouse wastes, such as blood, waste meat, bones, hoofs, hair, tainted meat, diseased animals, and tankage or residue from rendering and glue-making processes. In converting these substances into commercial fertilizer, blood is dried at a moderate heat and crushed to powder; bones may be ground without preliminary treatment, or they may be treated with a volatile solvent or boiled with steam to remove fats and gelatin and then ground for fertilizer; and tankage is dried, powdered, and mixed with other fertilizing material. The valuable ingredients sought for in all stock are nitrogen, potassium, and phosphorus.

Glue is prepared from animal tissues, which on heating with water lose their structure, swell up, and finally go into solution. When they become cool, such solutions form a jelly which dries into the hard translucent mass known as glue. The raw material includes hide trimmings, "skivings," "fleshings," and other untanned refuse of the tannery; earlaps, heads, feet, tails, and other slaughterhouse

offal; and "green" or fresh bones. Green bones are used in manufacturing "bone glue;" the other materials are used for the production of "hide glue."

The stock for hide glue is salted, washed, and then mixed with milk of lime and allowed to stand for several weeks. The liming softens and swells the tissues, converts the fats into lime soaps, and dissolves a large part of the blood, flesh, coriin and other matters which will not form glue. The material is then washed in water and acid. The sewage from liming and washing is largely used for fertilizer.

Bone glue is not essentially different from hide glue. The fatty matters are removed from the fresh bones by boiling with water and skimming or by extracting with a volatile solvent. The bones are then crushed and treated with dilute acids to remove calcium phosphate and other salts, which are valuable as fertilizers. Washing with lime water removes traces of acid.

The stock for bone or hide glue, having been cleansed by the treatment just described, is boiled with water or steamed in a digester until practically all the glue-forming material has been dissolved. Several successive boilings may be used. The glue solution is filtered, evaporated to the desired consistency in a vacuum pan, and run into trays in which it cools and forms a jelly, which is cut into plates and dried for market.

It may be seen from the foregoing description that the industries of making oleomargarine, fertilizer, and glue are closely allied. The raw materials are the wastes from slaughterhouses and markets. The processes, however, vary greatly in different establishments. In one plant utilizing these raw materials attention may be given to the manufacture of a single product. In another plant all by-products may be taken into account and the sewage or waste waters from one process may be utilized to the fullest extent as raw materials for the manufacture of a secondary product. A detailed description of processes would not, therefore, be of general application, and variation in concentration and in difficulty of purification of waste waters is to be expected with variation in processes and products of manufacture. The L. B. Darling Fertilizer Company, at whose establishment experimental work was conducted, attempts to recover the greatest possible amount of valuable material from the stock that is used; consequently, the waste waters are small in quantity and low in concentration as compared with the sewage from plants that are less economically operated.

Practically the only waste from this plant, and the waste that was used in the experimental work, was the discharge over a weir in the last of a series of boxes, or tanks, through which a waste liquor was passed for the purpose of increasing the recovery of fat and animal

tissue by gathering the scum and the sediment. This liquor is a waste from "tankage," and the greater part of the fatty matter has been taken from it before it is run into the boxes. The writers have found no account of experimental filtration of a waste similar to that from the series of skimming tanks. It is a putrescible, ill-smelling liquor, very high in organic matter in solution and in suspension, both carbonaceous and nitrogenous. The nitrogen content is enormous, because of the animal composition of the materials used at the plant. It is extremely high in bacterial life, the number of organisms per cubic centimeter being invariably in the millions. The average for ten samples is 13,800,000 bacteria per cubic centimeter. Other characteristics are high turbidity, very great sediment, and a dirty-brown color.

Analyses of samples of this waste show that it is extremely variable in strength. Twelve samples give an average figure for organic nitrogen of 979 parts per million, and for oxygen consumed of 988 parts per million. The detailed analyses are given in Table 42.

TABLE 42.—*Analyses of waste water from factory of L. B. Darling Fertilizer Company.*

[Milligrams per liter.]

Date.	Time.	Residue on evaporation.			Nitrogen as free ammonia.	Total organic nitrogen.	Nitrogen as—		Oxygen consumed.	Fats.	Number of bacteria per cubic centimeter.
		Total.	Loss on ignition.	Fixed.			Nitrates.	Nitrites.			
1907.											
April 24	11.00 a. m.	5,744	4,836	908	79	500	.....	.....	500	575	.....
May 28	(a)	7,596	6,604	992	123	726	.....	.....	475	1,240	25,000,000
July 22	11.30 a. m.	[b] 5,046 [c] 3,598	[b] 4,344 [c] 2,961	[b] 702 [c] 637	105	[b] 386 [c] 259	0.00 (?)	2.000	[b] 470 [c] 340	1,996	13,300,000
August 8	10.00 a. m.	[b] 13,352 [c] 11,824	[b] 11,468 [c] 10,148	[b] 1,864 1,676	254	1,916	.....	.000	1,150	.....	18,000,000
August 20	a. m.	.....	.....	.....	170	1,310	Trace (?)	.000	990	.....	13,500,000
August 28	10.30 a. m.	.....	.....	.....	209	1,036	Trace (?)	2.000	1,380	.....	4,400,000
September 11	10.00 a. m.	.....	.....	.....	248	603	.00 (?)	2.400	440	.....	13,800,000
September 18	10.00 a. m.	.....	.....	.....	108	660	.....	.....	745	.....	7,000,000
October 10	10.00 a. m.	.....	.....	.....	117	962	.....	.....	990	.....	16,500,000
October 17	10.00 a. m.	.....	.....	.....	166	1,332	.00 (?)	2.400	1,910	.....	18,800,000
November 1	9.45 a. m.	.....	.....	.....	172	1,434	.....	.....	1,600	.....	.....
November 13	10.30 a. m.	.....	.....	.....	127	886	.50 (?)	2.000	1,200	.....	7,900,000

[a] Composite of samples taken hourly from 8 a. m. to 6 p. m., inclusive. [b] Unfiltered. [c] Filtered.

EXPERIMENTAL PURIFICATION OF WASTES.

OPERATION OF PURIFICATION PLANT.

Sand filtration without preliminary treatment was conducted from July 26 to November 14, 1907. Two galvanized-iron filters, 20 inches in diameter, were kept in operation, out of doors and uncovered, throughout the period. Both filters contained 4½ feet of sand, having an effective size of 0.23 millimeters and a uniformity coefficient of 3.4. Three or four inches of fine cinders, not screened and containing a little dust, supported the sand, and these cinders in turn rested on 8 or 10 inches of larger cinders.

Filter No. 1 was started at the rate of approximately 20,000 gallons per acre per day. This dose, applied once a day for six days in the week, was continued till August 21, when it was increased to 100,000 gallons a day. The dose was made 40,000 gallons a day on September 12, and it was decreased to the original dose of 20,000 gallons a day on October 22. The surface of the filter was not raked during the run, except when removals of sand were made, at which time the surface was leveled before dosing the filter was resumed. The behavior of this filter demonstrated that surface clogging occurs at any of the rates that were tried and that the interval between cleanings is dependent on the size of the dose, being necessarily more frequent with the higher rates. While the rate of dosing was 100,000 gallons a day the filters clogged so badly that it was difficult to apply the entire dose from day to day, because so much of the previous dose was left on the filter that there was not room above the sand for more liquor.

The condition of the surface finally became so bad, the sand being discolored and covered with a slimy deposit, that it became necessary, on September 11, to remove about 1½ inches of the sand on top. No new sand was put on, but the surface was leveled. Dosing was resumed, but at the rate of 40,000 gallons. The same condition of slow drying soon developed, and conditions became such that the surface would not dry from day to day. Consequently a slimy layer about one-eighth inch thick, which sealed the surface, together with half an inch of the top sand, was removed on October 21, and the surface was leveled after the top layer of 3 to 4 inches had been mixed. No new sand was put on, and dosing was resumed at the 20,000-gallon rate. By the middle of November surface clogging was again apparent, and the filter was gradually approaching the condition noted on previous occasions. When the filter was dismantled on December 13 dosing had been discontinued about ten days. The sand was clean in appearance, there being little discoloration. The clogging was caused by a surface deposit, grayish in color, and not more than one-sixteenth to one-eighth inch thick after it had dried into the top sand.

Filter No. 2 was started at a rate of 60,000 gallons an acre. Dosing once daily for six days a week was continued until October 22. From that date until the dismantling of the filter the dose was applied every other day at the rate of 40,000 gallons per acre per day, making the net rate for the latter period 20,000 gallons per acre per day. An inch of sand was removed from the surface of the filter on September 11, after which dosing was resumed without putting on new sand. Sand was again removed on October 21, as a slimy layer about one-eighth inch thick was sealing the surface at this time. This top layer and about one-half inch of sand was removed; the surface was then leveled, and after the top layer of 3 to 4 inches of sand had been mixed dosing was resumed without putting on new sand. The conditions after that date were similar to those existing in filter No. 1, and the appearance of the sand when the filter was dismantled on December 13 was much the same as that of the sand in the other filter.

When the experiments were discontinued samples of sand were collected from both filters at the top inch, at 6 inches down, and at the bottom. The results of tests for albuminoid ammonia and loss on ignition on these samples are given in Table 43. They confirm what was noticed regarding the satisfactory condition of the sand below the surface at the time of dismantling. The analyses of the samples from the top inch indicate the presence of a large amount of nitrogenous organic matter in the clogging film.

TABLE 43.—*Partial analyses of sands after use in filtration.*

Source of sample.	Albuminoid ammonia.	Loss on ignition.
	Milligrams per liter.	*Per cent.*
Filter No. 1:		
Top inch	[a]3,156	12.1
6 inches down	145	.67
Bottom	87	.47
Filter No. 2:		
Top inch	2,262	7.3
6 inches down	147	.57
Bottom	124	.51

[a] Probably too low.

The quality of the effluents from the filters, as determined by analyses of samples taken at about 10 a. m., is shown in Table 44.

TABLE 44.—*Analyses of effluents from filters Nos. 1 and 2 at the establishment of the L. B. Darling Fertilizer Company.*

FROM FILTER NO. 1.

[Milligrams per liter.]

Date.	Appearance.			Odor.	Nitrogen as free ammonia.	Total organic nitrogen.	Nitrogen as—		Oxygen consumed.	Number of bacteria per cubic centimeter.	Net rate of filtration (gallons per acre per day).
	Turbidity.	Sediment.	Color.				Nitrates.	Nitrites.			
1907.											
August 1	Decided	Very heavy (iron).	Red	Distinctly unpleasant.	119	67.2	1.00(?)	Trace.	68.0		20,000
August 8[a]	Slight	Heavy (iron)	Iron	do	320	35.7	Trace(?)	0.50 (?)	62.0	50,000	20,000
August 20	Decided	Slight (iron)	Very light brown	do	502	11.5	Trace(?)	5.500	36.0	140,000	20,000
August 28	Great (iron)	do	Red (iron)	Decidedly unpleasant.	420	14.8	Trace(?)	.000	50.0	38,000	100,000
September 11	Very great (iron)	Heavy (iron)	Red	Distinctly unpleasant.	895	41.5	(?)	.000	87.0	20,000	100,000
September 18	do	do	Red (iron)	do	699	17.9	.00(?)	.000	109.0	500,000	40,000
October 10	do	do	Red	Faintly unpleasant	701	52.8	.00(?)	.000	135.0	310,000	40,000
October 17	Decided (iron)	Considerable (iron).	do	Distinctly unpleasant.	527	24.8	.00(?)	.000	118.0	400,000	40,000
November 1	Very decided	None	Reddish brown	Decidedly unpleasant.	661	43.5	1.00(?)	.000	150.0		20,000
November 13	do	do	do	Distinctly unpleasant.	624	25.9	.50(?)	.000(?)	130.0	190,000	20,000

FROM FILTER NO. 2.

1907.											
August 1	Decided	Heavy	Turbid	Distinctly unpleasant.	271	46.7	0.50(?)	Trace.	54.0		60,000
August 8[b]	Slight	Heavy (iron)	Iron	Distinctly unpleasant and moldy.	509	12.7	Trace (?)	0.050(?)	46.0	40,000	60,000
August 20	do	do	Red (iron)	Distinctly unpleasant.	626	10.7	Trace (?)	.000	65.0	40,000	60,000
August 28	Great (iron)	Slight (iron)	do	Decidedly unpleasant.	831	26.9	Trace (?)	.000	86.0	1,400,000	60,000
September 11	Decided (iron)	Considerable (iron).	Light brown	Distinctly unpleasant.	536	14.4	(?)	.000	70.0	4,200,000	60,000
September 18	Decided	Very slight	do	do	710	17.7	.00(?)	.000	110.0	450,000	60,000
October 10	Very great (iron)	Heavy (iron)	Red	Faintly unpleasant	560	12.8	.00(?)	.040	72.0	1,000,000	60,000
October 17	Decided (iron)	Considerable (iron).	do	Distinctly unpleasant.	740	19.7	.00(?)	.000	118.0	4,900,000	60,000
November 1	Very decided	None	Reddish brown	Decidedly unpleasant.	822	29.2	1.00(?)	.020(?)	150.0		20,000
November 13	Decided	do	Yellowish brown	Distinctly unpleasant.	658	22.0	.70(?)	.000(?)	115.0	400,000	20,000

[a] Residue on evaporation: Total, 1,486; fixed, 1,064; loss on ignition, 422.

[b] Residue on evaporation: Total, 1,908; fixed, 1,268; loss on ignition, 640.

Experiments were made with the object of coagulating the waste with chemicals in order to obtain a decided removal of organic matter before filtration, but the results were not satisfactory. The addition of aluminum sulphate resulted in excellent clarification on several occasions, but at other times the coagulum had no effect whatever, and the addition of soda ash did not aid coagulation. Copperas and lime also were tried, but the results were not encouraging.

RESULTS OF FILTRATION.

A summary of the determinations of organic nitrogen, organic nitrogen plus free ammonia, and oxygen consumed for the filter effluents, together with the percentage of removal by filtration represented by these estimates, is given in Table 45.

TABLE 45.—*Summary of results of filtration at the establishment of the L. B. Darling Fertilizer Company.*

Source of sample.	Number of samples analyzed.	Number of doses weekly.	Net rate of filtration (gallons per acre per day, approximately).	Milligrams per liter.			Percentage of removal.[a]					
				Organic nitrogen.	Organic nitrogen + free ammonia.	Oxygen consumed.	Organic nitrogen.		Organic nitrogen + free ammonia.		Oxygen consumed.	
							A.	B.	A.	B.	A.	B.
Crude waste	12			979	1,136	988						
Effluent, filter 1	3	6	20,000	38	352	55	96	97	69	74	94	94
Do	2	6	100,000	28	686	69	97	97	40	34	93	92
Do	3	6	40,000	32	674	121	97	97	41	40	88	88
Do	2	6	20,000	35	678	140	96	97	40	48	86	90
Effluent, filter 2	8	6	60,000	20	618	78	98	98	46	49	92	92
Do	2	3	20,000	26	766	133	98	98	33	42	86	90

[a] Columns A are calculated from the average of 12 samples of crude waste as a basis, but columns B are calculated from the samples of crude waste that were collected when the corresponding samples of filter effluent were taken.

The figures for percentage of removal, based on the estimates of organic nitrogen and oxygen consumed under widely different rates of filtration, are almost uniformly high. The decomposition of organic nitrogen is nearly the same in all cases, but the completeness of the oxidation, indicated by free ammonia, varies, showing some advantages in favor of the lower rates of filtration. The operation and the condition of the filters themselves are the proper sources of information regarding the best rates to use.

A high percentage of removal of organic matter can be effected by filters, but constant attention to the surface of the sand, with frequent scraping and ultimate addition of new sand, would be necessary. It is doubtful whether, with the rate as low as 20,000 gallons, filters would do satisfactory work longer than five or six weeks unless attention were given to the surface. It is possible that a rate of

60,000 gallons could be used, but conditions requiring slight sand removal in less time than a month would probably result. If attention were not given to the surface when needed, a nuisance would probably result from the odors given off by the putrid waste, but if the surface were kept fairly open, thus allowing the liquor to get quickly below the surface, such trouble might be avoided. Preliminary filtration at a rate of about 60,000 gallons, followed by a second filtration at the same or even a little higher rate, would give excellent results.

It would be advisable to construct near the filters a storage or dosing tank capable of holding one day's flow, in order to avoid the necessity of continual discharge on the surface of the sand. Considerable sediment and scum would, of course, collect in the storage tank, and the supernatant liquor would not clog the sand nearly so rapidly as the waste itself. The interval between scrapings would also be longer, and the accumulated scum and sediment could be treated like the material now recovered in the series of tanks. If filtration were interrupted by severe winter weather, such conditions would prevail only for a comparatively short period and that at a time when the crude waste would do least damage to a stream. The waste liquor, even then, would be considerably reduced in strength by sedimentation in the storage tank, which would increase the organic matters returned for utilization.

COSTS OF FILTRATION.

Table 46 gives estimates of the costs of installation, operation, and maintenance of a plant for purifying tank waste from establishments similar to that of the L. B. Darling Fertilizer Company. The estimates are based on the results of experiments with the waste from the factory just mentioned. The installation provides for sand filtration and for a tank for storing one day's supply of liquor, 25,000 gallons.

TABLE 46.—*Estimates of cost of plant for filtering tank waste.*

Net rate of filtration (gallons per acre per day).	Filtration area.	Cost of plant.	Annual cost of maintenance and operation.	Cost per 1,000 gallons.
	Acres.			*Cents.*
10,000	2.50	$11,000	$2,200	29.3
20,000	1.25	6,000	1,200	16.0
40,000	.625	3,500	700	9.3
60,000	.417	2,700	540	7.2
100,000	.250	2,000	400	5.3

The cost of operation and maintenance is based on fixed charges of 15 per cent of the cost of the plant for interest, repairs, and depreciation, and 5 per cent for labor. This makes ample allowance for the high concentration of the waste, for usually the charges are about 11 per cent and 3 per cent, respectively, for sewage-treatment plants of this type. The tank capacity that is provided allows for considerable sedimentation and for a dosing tank.

EVAPORATION—RECOVERY TREATMENT OF WASTES.

VALUE OF RECOVERED PRODUCT.

Table 47 gives estimates of the fertilizing value of the products obtained by evaporating and drying 25,000 gallons of tank waste daily. The unit values for nitrogen, phosphoric acid, and potash are those proposed by the Massachusetts agricultural experiment station.[a]

TABLE 47.—*Estimated value of products obtained by evaporating and drying tank waste.*

VALUES BASED ON A COMPOSITE SAMPLE COLLECTED JUNE 16, 1908.

	Milligrams per liter.	Pounds per 1,000 gallons.	Value per pound.	Value per 1,000 gallons.	Value per day.
Organic nitrogen (N)	595	4.96	$0.185	$0.918	$22.94
Phosphoric acid (P_2O_5)	106	.88	.05	.044	1.10
Potash as K_2O	126	1.05	.05	.052	1.31
Total solids	5,300	44.2	.023	1.014	25.35
Volatile solids	4,190	34.9	.026	.918	22.94
Fixed solids	1,110	9.3	.010	.096	2.41

VALUES BASED ON AN AVERAGE OF TWO COMPOSITE SAMPLES AND A MEAN OF 11 SNAP SAMPLES.

Organic nitrogen (N)	774	6.45	$0.185	$1.195	$29.88
Phosphoric acid (P_2O_5)	[a] 138	1.15	.050	.058	1.44
Potash as K_2O	[a] 164	1.37	.050	.068	1.71
Total solids	[a] 6,900	57.5	.023	1.321	33.03
Volatile solids	[a] 5,450	45.4	.026	1.195	29.88
Fixed solids	[a] 1,450	12.1	.010	.126	3.15

[a] Estimated from ratio to nitrogen in sample of June 16, 1908.

This shows the value of the waste based on the average to be $1.32 per 1,000 gallons.

COST OF TREATMENT.

The next natural question is the cost of installation of a complete independent plant operating ten hours a day and a similar estimate for the plant probably required as an addition to a factory. These figures are as follows:

[a] Bull. No. 51, March, 1894.

Estimated cost of plant for evaporating and drying 25,000 gallons of tank waste daily.

Complete independent plant:	
Boilers and setting, flues, stack, feed pumps, coal pocket, piping, and heaters	$8,000
Evaporator (triple-effect)	10,000
Dryer	500
Building	3,500
Incidentals	2,000
	24,000
Plant probably required as an addition to a factory:	
Boilers and setting, flues, feed pumps, piping, and heaters	5,400
Evaporator (triple-effect)	10,000
Building	1,000
Incidentals	1,500
	17,900

The cost of operation of both of the above-described plants, the complete plant and the probable addition to the existing plant, is of course the figure to determine the practicability of the recovery process as applied to the waste. These estimates are as follows:

Estimated cost of operation of plant for evaporating and drying 25,000 gallons of tank waste daily.

Complete independent plant:	
Fixed charges (11 per cent)	$2,607.00
Attendance ($33 per week)	1,716.00
Coal (1,500 tons, at $4.50)	6,750.00
Supplies	227.00
Total annual cost	11,300.00
Cost per day	37.67
Cost per 1,000 gallons	1.51
Plant probably required as an addition to a factory:	
Fixed charges (11 per cent)	1,969.00
Attendance ($17 per week)	884.00
Coal (1,500 tons, at $4.50)	6,750.00
Supplies	227.00
Total annual cost	9,830.00
Cost per day	32.77
Cost per 1,000 gallons	1.31

CONCLUSIONS.

As the value of the waste per 1,000 gallons and the estimated cost of operating the plant which would be required as an addition are practically identical, evaporation would just about pay for itself at this plant were the strength of the waste maintained at about total solids—6,900 parts per million and organic nitrogen 774 parts per million.

Reference to Table 47 shows that an increase of 52 parts per million in total solids adds 1 per cent per 1,000 gallons to the value of the waste. If, therefore, the more dilute portions could be diverted and only the more concentrated liquor used in the evaporation plant, a small profit would undoubtedly be obtained. The figures for the complete independent plant indicate that a waste containing 7,900 parts per million total solids would be valued at $1.51 per 1,000 gallons, or the cost of operation of this plant. Thus a waste of greater strength than the one just mentioned and of the same character as that with which the experiments were made could be handled with a margin of profit in an independent plant.

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DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

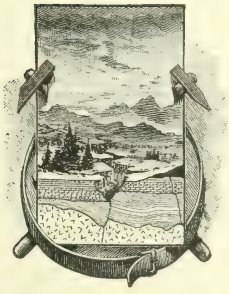
WATER-SUPPLY PAPER 236

THE QUALITY OF SURFACE WATERS IN THE UNITED STATES

PART I.—ANALYSES OF WATERS EAST OF THE ONE HUNDREDTH MERIDIAN

BY

R. B. DOLE



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THE QUALITY OF SURFACE WATERS IN THE UNITED STATES.

PART 1.—ANALYSES OF WATERS EAST OF THE ONE HUNDREDTH MERIDIAN.

By R. B. Dole.

INTRODUCTION.

In the present period of increased scrutiny and careful analysis of the production costs of industrial processes manufacturers are giving more attention than formerly to the quality of water supplies, because water in some form is necessary for the operation of every industrial establishment. During the last twenty years the practical man has been obliged to modify his views, previously limited only by the quantity of available water, by considering the part of his manufacturing cost that is due to the use of water unsuited to his processes. In the adoption of water for domestic supply one of the most important features that affects its value is its potability, which is determined principally by its freedom from dangerous, ill-smelling, or bad-tasting organisms. In the application of water to industrial use, however, biologic features are usually secondary in importance, and the suitability of the supply depends on the amount of mineral matter that is dissolved or suspended in it. This is especially true of waters which are used for steam making, for paper manufacture, and for some other processes. The hygienic quality, as well as the physical and chemical characteristics, must be given due weight in some industries, such as starch making, brewing, distilling, and ice manufacture, but the industrial water problem is primarily a consideration of the mineral substances contained in the supplies. As water dissolves more or less of everything with which it comes in contact, natural waters contain a great variety of matter in solution and in suspension, and their relative purity depends on the locality from which they come. Waters that have percolated through limestone are hard; those that have traversed regions of alkali are alkaline; the run-off from swamps is colored and contains much organic

matter; the drainage from populated districts is polluted by disease-bearing organisms that render it unpotable. It is essential, therefore, to study the composition of river waters and their adaptability to different industrial processes.

The tremendous importance that the mineral quality of water has attained in these fields led the Geological Survey to undertake a detailed study of the quality of industrial water supplies, both surface and underground, and it became advisable during this investigation to procure information regarding the chemical composition of the waters of the lakes and streams of the United States. This volume, which forms Part 1 of the complete report, presents the detailed results of analyses of surface waters east of the one hundredth meridian. It gives merely the methods of analysis, the location of the sampling stations, and the analytical results, because the demand for the data has been great enough to justify the publication of the analyses before their detailed discussion. Part 2 will discuss the analyses in relation to stream flow, climate, forestation, geologic environment, pollution, and other factors. Another report now in preparation will consider the quality of the waters in special reference to their availability for industrial use, and a paper on chemical denudation in the United States will discuss aqueous erosion in relation to geologic time. For river waters in Illinois only the average chemical composition is given in the present volume, as detailed analyses of the waters from that State, with discussions, are to be included in a separate report.

PREVIOUS INVESTIGATIONS.

A few series of analyses representing samples of water collected systematically from some rivers and lakes in the United States have been published. The greater part of such work, however, has been performed for the purpose of obtaining information regarding the potability of water supplies rather than regarding their availability for industrial use, and as a result of this somewhat one-sided activity the data have reference to inorganic constituents only through determinations that are more or less incidental in sanitary water analysis. Yet the information in work of that character, especially in respect to estimates of total solids, chlorine, hardness, alkalinity, and iron, is valuable in general comparisons and is worth the attention of those who are interested in the mineral characteristics of waters. Especially valuable investigations of this nature have been conducted at Boston, Mass.,[a] Lawrence, Mass.,[b] New Orleans, La.,[c] New York,

[a] Boston Water Board, Ann. Repts., 1880 et seq.
[b] Reports of the Lawrence sewage experiment station.
[c] Sewerage and Water Board Report, New Orleans.

N. Y.,[a] Louisville, Ky.,[b] Cincinnati, Ohio,[c] St. Louis, Mo.,[d] and in Massachusetts,[e] Ohio,[f] and Illinois.[d]

Several hundred more or less complete analyses of surface waters can be found in the bulletins, water-supply papers, and other reports of the United States Geological Survey, in reports of state geological surveys, in bulletins of agricultural experiment stations, and in publications of scientific societies. Probably a still larger number remain unpublished in the hands of railroad and other industrial chemists, to whom the composition of water supplies is extremely important. All such data, though they are usually excellent in quality and undoubtedly valuable in many respects, are limited in their application, because the small number of samples that were collected from each source make it doubtful whether figures representing even approximately the maximum and minimum conditions of quality were encountered and whether averages of such analyses represent the average chemical composition of the waters considered.

The serial analyses of waters from the Rio Grande at Mesilla, N. Mex., by Goss,[g] and from Colorado River at Yuma and Salt River at Mesa, Ariz., by Forbes and Skinner,[h] deserve separate mention. In 1906 and 1907 series of samples of water from streams in the arid States were analyzed for the Reclamation Service by C. H. Stone and F. M. Eaton under the direction of W. H. Heileman, but the results of that study have not yet been published.

HISTORY OF THE PRESENT INVESTIGATION.

In the spring of 1905 arrangements were effected under which samples of water from Androscoggin River at Brunswick, Me., were collected for a year and analyzed by Prof. F. C. Robinson, of Bowdoin College, and from Mississippi River at New Orleans, La., by J. L. Porter, of the New Orleans Water and Sewerage Board. In the winter of 1905–6 a cooperative agreement between the United States Geological Survey and the State Board of Examiners of California was effected, under which samples of river water were collected at 20 stations in that State, united in sets of ten, and analyzed. This cooperation continued for one year and was resumed in the fall of

[a] Report of the commission on additional water supply of the city of New York, 1904.

[b] Fuller, G. W., Report on the investigations into the purification of the Ohio River water at Louisville, Ky., 1898.

[c] Board of trustees and commissioners of waterworks, Cincinnati: Report on the investigation into the purification of the Ohio River water for the improved water supply for the city of Cincinnati, Ohio, 1899.

[d] Reynolds, A. R., Report of streams examination of the waters between Lake Michigan at Chicago and the Mississippi River at St. Louis, 1902. Long, J. H., Chemical and bacterial examinations of the waters of the Illinois River and its tributaries; report of the sanitary investigations of the Illinois River and its tributaries: Illinois State Board of Health, 1901. Palmer, A. W., Chemical survey of the waters of Illinois: Report for the years 1897–1902, University of Illinois, 1903.

[e] Massachusetts State Board of Health, Ann. Repts., 1890 to date.

[f] Ohio State Board of Health, Ann. Repts., 1898 to date.

[g] Goss, Arthur, Bull. New Mexico Agr. Exper. Sta. No. 34, 1900.

[h] Forbes, R. H., and Skinner, W. W., Bull. Univ. Arizona Agr. Exper. Sta. No. 44, 1902.

1907, when several new stations were established for daily collection of water samples. Sixty-two stations were established in July, 1906, for the daily collection of samples of water from the principal rivers east of the one hundredth meridian, and arrangements were made for the collection of monthly samples from each of the Great Lakes and from St. Lawrence River. Shortly after that time a cooperative agreement was effected with the Illinois State Water Survey, the State Geological Survey of Illinois, and the engineering department of the University of Illinois for the purpose of investigating the quality of surface waters in that State, and 26 sampling stations were maintained for one year. A similar arrangement was made at the same time with the Kansas State Board of Health and the University of Kansas, and 24 stations for the collection of daily samples of river water were maintained in Kansas also for one year. The entire investigation was made under the direction of M. O. Leighton, chief hydrographer of the United States Geological Survey.

The samples collected in the New England, Middle, and East-Central States were shipped to Washington, D. C., where they were analyzed by R. B. Dole, M. G. Roberts, Chase Palmer, and W. D. Collins, of the Survey. Samples collected in the Southern States were shipped to Athens, Ga., and were analyzed in a branch laboratory at that point by J. R. Evans. When this laboratory was discontinued in May, 1907, part of the samples were transferred to a laboratory maintained at Norfolk, Va., where they were analyzed by W. D. Collins. The analyses of waters from the Middle-Western States, except Illinois and Kansas, were made in a branch laboratory at Iowa City, Iowa, by W. M. Barr, H. S. Spaulding, and Walton Van Winkle. The Illinois analyses were performed in the laboratory of the state water survey at Urbana, Ill., by W. D. Collins and C. K. Calvert. The Kansas samples were shipped to Lawrence, Kans., where they were tested in the laboratory of the University of Kansas by F. W. Bushong and A. J. Weith, under the direction of E. H. S. Bailey. The analyses of waters collected in California during 1906 were made in the Reclamation Service laboratory at Berkeley, by F. M. Eaton and P. L. McCreary, chemists detailed by the Geological Survey. The California analyses during 1907–8 were made in the same laboratory by Walton Van Winkle. The gage-height data, chiefly from field work under the direction of J. C. Hoyt, were collated by Herman Stabler.

ACKNOWLEDGMENTS.

So much voluntary assistance was accorded this work that reference by name to all the cooperators is impracticable. More than half the daily samples were collected absolutely free of charge under the direction of superintendents of waterworks and by other per-

sons interested in the work. Special acknowledgment is due to the Weather Bureau, United States Department of Agriculture, for the collection of water samples in South Carolina, Georgia, and Alabama, and for the privilege of using several series of gage heights. Through the courtesy of the authorities in charge at the University of Iowa and the University of Georgia the Survey was furnished with laboratory space and other facilities for the efficient performance of analytical work. The University of California has furnished quarters for the laboratory at Berkeley since its establishment in the spring of 1905.

The cooperative agreements between the Geological Survey and the state authorities in California, Illinois, and Kansas have made possible much more extended studies of the quality of surface waters in those States than could otherwise have been undertaken.

METHODS OF EXAMINATION.

GENERAL DISCUSSION.

Discussion of the chemical analysis of waters has formed an appreciable part of technical literature for many years, and the subject has been attractive to original investigators everywhere. All sorts of methods for testing water have been recorded in scientific literature, and many of them have survived practical use. It seems, therefore, neither profitable nor particularly interesting to present in great detail the manipulative technique of water analysis, and this discussion has been confined more particularly to other phases of the problem. Though the literature in respect to methods is abundant, comparatively little is said regarding the magnitude of the errors in common practice, the limitations of the methods, and their general application; consequently, the following account gives only outlines of the methods that were employed, with notes of departures from usual practice, but it considers in detail the errors of the determinations and their general availability. It was known at the commencement of the investigation that surface waters are different from one another in their mineralization, and that the concentration of the waters changes from time to time. The object of the laboratory work was to measure those differences and changes in quantitative terms accurately enough for geologic and industrial interpretation. When a chemist is examining mineral waters that are sold as beverages, he usually considers time and expense to be secondary in importance and he is enabled to avail himself of the highest refinements of analytical skill; but when he is testing waters from rivers that may change 100 per cent in their mineralization while he is examining one sample, he is not justified in employing such accurate procedure, and the cost of it is prohibitive

when a large number of samples is involved. Estimates of the amounts of the constituents within 5 to 10 per cent are usually accurate enough for industrial purposes, and that degree of refinement is sufficient for studying fluctuations in the quality of nearly all surface waters. It was felt that in the present investigation methods should be selected that would be sufficiently accurate, fairly inexpensive, rapid in execution, and productive of results available for the greatest number of purposes. With these facts in mind, therefore, procedures were adopted for estimating the principal acids and bases with moderate accuracy. None of the methods is new, and most of them have been recognized by competent authority.

COLLECTION OF SAMPLES.

One 4-ounce bottle of water was collected daily from the stream at each river station and was mailed to a designated laboratory. Empty bottles, thoroughly cleaned and inclosed in mailing cases, were supplied from the laboratories, and the samples were shipped as soon as possible after collection. The sampling stations were established with the object of obtaining water as nearly representative as possible of the average stream flow. If bridges were near at hand the bottles were filled in midstream by lowering them into the water in suitable holders, and intake pipes also were utilized at a large number of stations. Where neither of these arrangements could be effected the samples were collected either from a boat or from the bank by attaching the bottle to the end of a long pole. When the samples were received at the laboratories, they were united in sets of ten consecutive samples, thus making for analysis a composite sample measuring about 1,100 cubic centimeters.

DIVISION OF COMPOSITE SAMPLE.

After the composite sample had been thoroughly mixed by shaking, portions were in general withdrawn as follows: For determination of suspended solids and for filtration, 500 cubic centimeters; for determination of nitrates, 50 cubic centimeters; for determination of chlorine, 100 cubic centimeters; for determination of carbonates and bicarbonates, 50 cubic centimeters. This left 410 cubic centimeters for reserve in case of accident. It was necessary to alter these amounts for some rivers; the principal changes were decrease of the amounts used for determining suspended solids and nitrates and increase of the amount used for determining total solids and certain dissolved constituents. As changes of that sort affect the accuracy of the estimates, they are noted in accounts of the determinations and in discussion of the probable errors.

TURBIDITY.

The determination of turbidity was made on part or on all of the sample, and, as this determination does not prevent the use of the water for other procedures, the sample withdrawn for this purpose could be returned to the bottle if desired. Usually, however, the turbidity determination was made after all the others and on the reserve portion. The Jackson candle turbidimeter [a] was used for estimating turbidities between 100 and 1,000 parts per million. Estimates of turbidities exceeding 1,000 parts per million were made on a portion of the sample properly diluted with distilled water. All turbidities have been referred to the regular silica standard recommended by the American Public Health Association,[b] which can be prepared by suspending 1 gram of thoroughly dried Pear's precipitated fuller's earth [c] in 1 liter of distilled water. Such a suspension has a turbidity of 1,000 parts per million and it gives a reading of 2.3 centimeters in the standard turbidimeter. Turbidities below 100 parts per million were estimated by comparison with well-shaken dilutions of this silica standard in 250 cubic centimeter bottles of clear, colorless glass.

The turbidimeter consists of a glass tube surrounded by a cylindrical brass holder supported by a stand, in the center of which is a standard English candle. The glass tube is polished at the bottom and is graduated in millimeters from the bottom upward. The candle is automatically adjusted by a spring so that its flame is always 3 inches below the bottom of the glass tube. The water in which the turbidity is to be estimated is poured into the glass tube until the image of the lighted candle below is just obliterated. The depth of the water in the tube, read across the bottom of the meniscus, is referred to a table which gives the turbidity of the water in parts per million of silica. The instrument is convenient for laboratory work, and as its source of light is the standard candle it is ready for use at all times. The candle should be kept properly trimmed and not be in a draft. The most accurate results are obtained by making the readings in a dark room rapidly, before the liquid has become heated to any extent. The comparison between the readings of the standard turbidimeter and the corresponding parts per million of suspended silica is given in Table 1.

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[a] Leighton, M. O., The field assay of water: Water-Supply Paper U. S. Geol. Survey No. 151, 1905, pp. 26-29.

[b] Report of the committee on standard methods of water analyses to the laboratory section: Public Health Association, Pub. Health Papers and Repts., vol 30, pt. 2, 1905, p. 16; also Jour. Infect. Dis., No. 1, May, 1905, p. 16.

[c] Levy, E. C., A ready method for preparing a silica turbidity standard: Pub Health Papers and Repts. Am. Pub. Health Assoc., vol. 31, pt. 2, 1905, p. 149.

TABLE 1.—*Reduction of readings with turbidimeter to parts per million of silica.*

Depth in centimeters.	Turbidity (parts per million of silica).	Depth in centimeters.	Turbidity (parts per million of silica).	Depth in centimeters.	Turbidity (parts per million of silica).	Depth in centimeters.	Turbidity (parts per million of silica).
2.3	1,000	5.6	390	7.5	290	11.4	190
2.6	900	5.8	380	7.8	280	12.0	180
2.9	800	5.9	370	8.1	270	12.7	170
3.2	700	6.1	360	8.4	260	13.5	160
3.5	650	6.3	350	8.7	250	14.4	150
3.8	600	6.4	340	9.1	240	15.4	140
4.1	550	6.6	330	9.5	230	16.6	130
4.5	500	6.8	320	9.9	220	18.0	130
4.9	450	7.0	310	10.3	210	19.6	110
5.5	400	7.3	300	10.9	200	21.5	100

The only difficulty experienced in this determination was partial agglomeration of suspended clay in some samples, and this probably could have been obviated by determining turbidity immediately after uniting the daily samples. The probable limits of accuracy of the determination are such that the observations are recorded as in Table 2.

TABLE 2.—*Probable limits of accuracy in turbidity observations.*

[Parts per million.]

Turbidity.		Recorded to nearest—
Not less than—	Less than—	
.....	50	Unit.
50	100	5 parts.
100	500	10 parts.
500	1,000	50 parts.
1,000	.....	100 parts.

TOTAL SUSPENDED SOLIDS.

Total suspended matter was determined by use of a Gooch crucible as described by Kimberley and Hommon.[a] A mat about one-sixteenth of an inch thick of iron-free, ignited asbestos was prepared in the bottom of a porcelain Gooch crucible of 25 cubic centimeters capacity fitted to a 1-liter filtering flask. Suction was applied and the mat was washed with distilled water until the filtrate was clear, after which the crucible was dried at 180° C. for one-half hour, cooled, and weighed. After the crucible had been replaced on the filtering flask and the mat had been moistened with distilled water, a measured portion of the sample was passed through it. The residue was washed with distilled water, the filtrate being allowed to run into

[a] Kimberley, A. E. and Hommon, H. B., The practical advantages of the Gooch crucible in the determination of the total and volatile suspended matter in sewage: Pub. Health Papers and Repts., Am. Pub. Health Assoc., vol. 31, pt. 2, 1905, p. 123.

the flask, and the crucible and residue were dried at 180° C. for one hour, cooled, and weighed. The difference in weight was computed to parts per million of suspended matter. Usually 500 cubic centimeters of water was used for this determination, but the suspended matter in many samples was so high that smaller portions had to be used, as little as 100 cubic centimeters being sometimes employed. Successful application of this procedure depends largely on the quality of the asbestos and on proper preparation of the mat. The asbestos should be finely shredded, thoroughly ignited, treated with strong hydrochloric acid for at least twelve hours, and then washed several times with distilled water. The mass should be shaken vigorously during these washings and allowed to settle about five minutes after each treatment, and the supernatant liquid containing the silt should then be decanted. Finally a fresh portion of water should be added and the mass should be shaken vigorously and about thirty seconds allowed for sedimentation of coarse particles. The asbestos should then be decanted from the sediment and preserved, suspended in water.

Amounts of suspended matter as small as 1 part per million were estimated, and the probable accuracy of the determination with a 500 cubic centimeter sample containing small amounts of suspended matter is within 1 part per million. The probable error is less than 10 per cent with suspended matters ranging from 100 to 5,000 parts per million. The determination presented no difficulties with most of the waters that were examined, but considerable trouble was experienced in removing the sticky "gumbo" that is suspended in many rivers of the Mississippi Valley. The material clogs the asbestos mat so badly that sometimes less than 50 cubic centimeters of water passes through. As small amounts as practicable were used in determining the suspended matter in such samples, and two or three crucibles were sometimes employed for filtering one sample. After the mat has become clogged, the surface of it can be loosened without injury by careful scraping with the point of a pencil or other sharp instrument, and filtration can proceed. It is also advantageous at times to use a thicker mat with coarse asbestos on the bottom and a finer quality on top. Loss of suspended matter by having it run through the mat occurred with some waters, but the amount of material that escaped was usually too small to constitute an appreciable source of error in the estimate of suspended solids.

TOTAL DISSOLVED SOLIDS.

Total dissolved matter was regularly determined on 500 cubic centimeters of the filtered sample, which was evaporated to dryness on the water bath in a tared platinum dish, dried at 180° C. for one hour, cooled and weighed. The residue was computed to parts per

million of total dissolved solids. If the filtrate from the determination of suspended solids was not sufficient for estimating total solids, as in the tests of very muddy waters, the rest of the required amount was filtered through paper. The only notable difficulty experienced in making this determination was that of obtaining a clear filtrate for evaporation, especially with the muddy waters of the Southern States. Part of the suspended matter in some southern rivers is so fine that it is not removed by filtration through either an asbestos mat or paper. Though the amount of suspended solids lost in that manner is so small that it does not materially affect the estimate of suspended solids, the weight of the material, when it is compared with the relatively small amount of dissolved matter in many waters, is great enough to constitute an error in the estimate of dissolved solids, and the suspended matter also causes trouble in subsequent operations on the residue. During the first part of the work waters were filtered as well as possible through asbestos mats, then through paper mats, thus reducing the residual suspended matter in most samples to less than 5 parts per million. In later work it was found advisable to remove all traces of suspended matter from such samples by the use of alumina cream. This reagent was prepared by precipitating aluminum hydrate from a solution of aluminum sulphate by means of sodium hydrate. The precipitate was thoroughly washed with distilled water till it showed only traces of sulphates, alkalies, and alkalinity, and was then dissolved in hydrochloric acid, reprecipitated, and again thoroughly washed. One or two cubic centimeters of the aluminum hydrate was shaken with the filtrate from the suspended matter, after which the precipitant was removed by filtration through paper. A perfectly clear filtrate was obtained for evaporation by that treatment.

The determination of dissolved solids was usually made with 500 cubic centimeters of water, but 250 cubic centimeters was used for some of the western rivers that are very high in dissolved matter, and 700 cubic centimeters was taken for nearly all the waters collected at the southeastern stations during the latter half of the period, because it seemed advisable to have as much residue as possible for analysis. The difference between duplicate determinations of dissolved solids was usually about 1 part per million, when 500 cubic centimeters of the sample was evaporated and when about 100 parts per million of dissolved matter was present. The difference is likely to vary in amount more with waters containing considerable organic matter or alkali than with waters containing calcium salts.

The committee on standard methods of water analysis[a] recommend that suspended and dissolved solids be dried at 103° C. for one-half hour. Many chemists employ a temperature of 105° C., and others

[a] Pub. Health Papers and Reports, Am. Pub. Health Assoc., vol. 30, pt. 2, 1905, p. 43.

dry residues in ovens surrounded by boiling water. Fresenius[a] recommends drying at 180° C. till the weight is constant, but as such long-continued desiccation was not practicable in these tests, the time was limited to one hour, though the temperature of 180° was adopted. The results seem to justify the use of the higher temperature. Practically all the water of crystallization and that mechanically occluded by residues of ordinary amount from waters of ordinary composition are driven off, and the organic matter is more or less carbonized and is greatly reduced in weight, though it is not completely destroyed. Drying at that temperature, therefore, makes comparison between the sum of the constituents and the amount of solids by actual determination more feasible than drying at the lower temperature. That the results of the analyses corroborate this belief is demonstrated on page 30 by comparisons between figures representing average total solids and those representing the average sum of the constituents. Another advantage of the higher temperature is that the results represent more nearly than those obtained at lower temperatures the conditions under which solids are deposited in steam boilers.

SILICA.

The residue from the determination of total dissolved solids, after being gently heated in a radiator until the organic matter was carbonized or wholly destroyed, was moistened with hydrochloric acid (1 to 1) and the dish, covered with a watch glass, was heated on the water bath for a few minutes. After treatment with acid had been repeated, if necessary, the sides of the dish were thoroughly rubbed down, and the mass was evaporated to dryness. The residue was again treated with 2 or 3 cubic centimeters of the acid and some distilled water, was heated on the water bath, and was finally separated from the solution by filtration through ashless filter paper. Little trouble was experienced in dissolving calcium sulphate in the residues. The insoluble part was thoroughly washed with hot water containing hydrochloric acid, ignited in a tared platinum crucible, cooled and weighed. It was then moistened with a few drops of sulphuric acid (specific gravity 1.84), and the silicia was volatilized with hydrofluoric acid, after which the crucible was again ignited, cooled and weighed. If the final residue exceeded 0.0005 gram, it was usually tested to discover its composition. The part volatilized by hydrochloric acid was computed to parts per million of silica (SiO_2). The nonvolatile residues were usually low, probably exceeding 0.0003 gram in less than 5 per cent of the analyses. They were highest in samples that were slightly turbid before evaporation, a condition indicating that part of the fine suspended matter left after filtration consisted of silicates that are not decomposed by hydrochloric acid.

[a] Fresenius, C. R., Quantitative chemical analysis (transl. of 6th German ed.), vol. 2, 1904, p. 245.

IRON.

The iron in the filtrate from the determination of silica was oxidized by boiling the solution with a few drops of nitric acid (specific gravity 1.42). After a slight excess of ammonium hydrate had been added, the liquid was heated for a few minutes to precipitate the oxides of iron and aluminum, which were then removed by filtration and washed with hot water containing a little ammonium chloride. If it was desired to determine aluminum, the precipitate was dried, ignited, and weighed, then fused with fused sodium bisulphate. The resulting mass was dissolved in dilute sulphuric acid (1 to 3) and the solution was filtered and boiled vigorously for two or three minutes with 1 cubic centimeter of nitric acid (1.42). It was then cooled and diluted with water, and the iron in it was determined colorimetrically. The amount of iron as Fe_2O_3, subtracted from the weight of the combined oxides, gives the Al_2O_3, which multiplied by 0.53 gives the aluminum (Al). If, however, it appeared from the bulk of the precipitate that the combined oxides of iron and aluminum amounted to less than 5 or 6 parts per million the determination of aluminum was omitted. In that case the precipitate was not ignited but was dissolved immediately in hydrochloric acid, 1 cubic centimeter of nitric acid (specific gravity 1.42) was added, the solution was boiled, and the iron was determined colorimetrically.

The ferric solution was diluted to 90 cubic centimeters with distilled water, 10 cubic centimeters of a 2 per cent solution of potassium sulphocyanide was added, the solutions were thoroughly mixed, and the color that developed was compared immediately with iron standards in Nessler tubes measuring 17.5 centimeters to the 100 cubic centimeter mark. The depth of the colors that were compared did not exceed that equivalent to 0.001 gram of Fe, and if it was necessary to divide the solution that operation was always performed before the addition of potassium sulphocyanide. Colors equivalent to amounts of iron between 0.001 gram and 0.0001 gram of Fe were matched by comparison with colored slides, the manipulation and accuracy of which have been discussed by the writer.[a] Colors equivalent to amounts of iron less than 0.0001 gram of Fe were compared with permanent iron standards made by mixing solutions of cobaltous chloride and potassium platinic chloride in proper proportion.[b]

Methods for the colorimetric determination of iron have been extensively studied by Stokes and Cain,[c] who have ascertained the

[a] Dole, R. B., Notes on the determination of iron: Pub. Health Papers and Repts., Am. Pub. Health Assoc., vol. 32, pt. 1, 1907, p. 183.

[b] Public Health Papers and Reports, Am. Pub. Health Assoc., vol. 30, pt. 2, 1905, p. 46; also Jackson, D. D., Tech. Quart. vol. 13, 1900, p. 315.

[c] Stokes, H. N., and Cain, J. R., On the colorimetric determination of iron with special reference to chemical reagents: Bull. Bur. Standards, U. S. Dept. Com. and Lab., No. 3, 1906, p. 115; also Jour. Am. Chem. Soc., vol. 27, 1905, p. 409; Chem. Abs., Am. Chem. Soc., vol. 1, 1907, p. 1955.

effect of certain substances and changes in technique on the intensity of the color that is developed in the sulphocyanate test. They also recommend several refinements in procedure. Special care was taken in the present investigation to make the estimate always in the same manner, and the iron group was separated from other components of the residue before the color comparisons were made. In nearly all the work the iron was precipitated from solutions representing 500 cubic centimeters of the sample, so that the probable accuracy of the estimates is somewhat greater than that of the estimates of iron usually made, for which 50 to 100 cubic centimeters of the sample is used.

CALCIUM.

The filtrate from the determination of iron was diluted to a definite volume, usually 100 cubic centimeters, and was divided into two equal parts. One part was used for the determination of calcium and magnesium and the other part for the determination of sulphates and alkalies. After the portion for the determination of calcium and magnesium had been heated to boiling in a beaker, it was made slightly alkaline with ammonium hydrate; ammonium oxalate in the form of hot 5 per cent aqueous solution was then added to it in sufficient amount to convert all the calcium and magnesium into oxalates. Ten cubic centimeters was usually added, but more was used if the figure for total solids indicated that this amount was not enough. The mixture was digested not less than three hours in order to precipitate all the calcium and to dissolve the magnesium oxalate. The solution was filtered through Schleicher and Schüll white ribbon paper No. 589, and the precipitate was washed with hot water containing a little ammonia, no special care being taken to transfer all the calcium oxalate from the flask to the funnel. The flask in which the precipitation was made was then placed under the funnel, and while the precipitate was agitated by a stream of hot water from a wash bottle dilute sulphuric acid (1 to 3) was poured on till the precipitate was completely decomposed and dissolved, after which the filter paper was thoroughly washed with hot water. If this operation is skillfully performed, the calcium precipitate is easily dissolved and 20 cubic centimeters of the dilute acid is amply sufficient for the purpose. The solution of calcium was diluted to about 100 cubic centimeters with hot distilled water and was titrated with N/20 potassium permanganate.

This method, described by Sutton,[a] was entirely satisfactory. The principal objections that had been advanced against its use are the difficulty of dissolving calcium oxalate in sulphuric acid and the

[a] Sutton, Francis, A systematic handbook of volumetric analysis, 9th ed., Philadelphia, 1904, p. 168.

errors introduced by traces of oxalic acid and organic matter. Solution of the precipitate is easy if it is performed in the manner just outlined, and this procedure is preferable to that recommended by Sutton, of punching a hole in the filter paper and washing the precipitate into the flask. The filter paper should never be digested in sulphuric acid, because the oxidizing power of the solution is unwarrantably increased by such treatment. The results of several experiments for the purpose of determining the errors due to solution of filter paper and to traces of oxalic acid indicate that it is possible to estimate calcium volumetrically within 1 part per million, when 250 cubic centimeters of the sample is used for the test. Schleicher and Schüll filter papers Nos. 595, 589, white ribbon, and 590 were treated exactly as if a calcium test were being made. Twenty cubic centimeters of dilute sulphuric acid was passed through each filter paper in a funnel, and the papers were then washed with hot distilled water until the filtrate amounted to about 100 cubic centimeters. When the acid solutions were titrated with N/20 potassium permanganate, the average amount of permanganate consumed by the solutions passed through No. 595 papers was 0.10 cubic centimeter; through No. 589, 0.09 cubic centimeter; and through No. 590, 0.06 cubic centimeter. The highest amount, 0.10 cubic centimeter, is equivalent for a 250 cubic centimeter sample to 0.4 part per million of calcium, an amount so small that it can be disregarded. In another experiment for the purpose of estimating the amount of oxalic acid that might be retained by the papers, 10 cubic centimeter lots of a 5 per cent solution of ammonium oxalate with 4 drops of nitric acid (specific gravity 1.42) and enough ammonium hydrate to make the mixture slightly alkaline were heated to boiling in an Erlenmeyer flask and filtered through different filter papers, which were afterwards washed with hot water till the filtrates failed to show the presence of chlorides. The filter papers were then treated with 20 cubic centimeters of sulphuric acid and washed, and the solutions were titrated with N/20 potassium permanganate. The average consumption of permanganate with No. 595 papers was 0.19 cubic centimeter; with No. 589 papers, 0.08 cubic centimeter; and with No. 590 papers, 0.08 cubic centimeter. The slight increase of permanganate for No. 595 papers over that used in the previous experiment is probably due to disintegration of this coarse-grained paper during washing. When samples of the three papers were torn into small pieces and were boiled for an hour in a 5 per cent sulphuric acid solution, the consumption of permanganate was notably increased, the amounts ranging from 0.2 to 0.3 cubic centimeter, but boiling the filter papers in sulphuric acid is not advised in the procedure and it is not necessary. If the precipitate is dissolved by pouring hot water

and dilute sulphuric acid through the paper, the consumption of permanganate solution by organic matter dissolved from the paper and by traces of oxalic acid left in it apparently does not exceed 0.10 cubic centimeter, an amount equivalent to 0.4 part per million of calcium in the regular procedure. The oxalic acid that may be occluded by the calcium oxalate was not estimated, but it is evident that this amount varies with the volume of precipitate, and the percentage of error is, therefore, no higher for low than for high calciums. The results of experiments comparing volumetric with gravimetric determinations also justify the conclusion that the volumetric method for estimating calcium is sufficiently accurate for general water analysis.

MAGNESIUM.

The filtrate from the calcium, having been made slightly acid with hydrochloric acid, was concentrated till the salts began to crystallize. An excess of a 10 per cent solution of sodium ammonium phosphate was added, and the liquid was allowed to cool. Finally it was made distinctly alkaline with ammonium hydrate and set aside not less than six hours in order to insure complete precipitation of the magnesium. Two cubic centimeters of strong ammonia (specific gravity 0.90) was usually sufficient in a volume of 50 to 75 cubic centimeters. Attention has been called by Gooch and Austin[a] to the fact that the large excess of ammonia which is so commonly added is distinctly disadvantageous. The precipitate was separated by filtration and was washed by decantation with water containing a little ammonia, till the excess of precipitant was removed. The precipitate in the beaker and on the paper was dissolved in 5 cubic centimeters of 5 per cent acetic acid and about 40 cubic centimeters of hot water. Five cubic centimeters of a 5 per cent ammonium acetate solution was added and the solution was titrated with standard uranium solution, care being taken to boil the solution vigorously before noting the final end point, which is found by adding a drop of the liquid to a drop of half-saturated solution of potassium ferrocyanide on a white porcelain plate.

This improvement on Sutton's method[b] of dissolving and titrating the phosphoric acid was devised and tested by M. G. Roberts. It is important to have a constant amount of solution, as the end point varies somewhat with the volume. The quantity of phosphate that is titrated should be such that 1 to 20 cubic centimeters of uranium solution may be added. The method was tested with satisfactory results by comparison with Sutton's procedure and with the usual gravimetric method.[c]

[a] Am. Jour. Sci., 4th ser., vol. 7, 1899, p. 187; also Bull. U. S. Geol. Survey No. 176, 1900, p. 65.
[b] Sutton, Francis, A systematic handbook of volumetric analysis, 9th ed., Philadelphia, 1904, p. 294.
[c] Fresenius, C. R., Quantitative chemical analysis (trans. of 6th German ed.), vol. 1, 1904, p. 275.

SULPHATE RADICLE.

The usual gravimetric method [a] was employed for the determination of sulphates. One-half the filtrate from the determination of iron was slightly acidulated with hydrochloric acid and was heated nearly to boiling. Excess of barium chloride in hot 10 per cent solution was then added, after which the liquid was digested on the hot plate for at least thirty minutes. The precipitate of barium sulphate was removed by filtration, thoroughly washed with hot water, dried, ignited, and weighed. The amount of sulphates as parts per million of SO_4 was computed from that weight.

SODIUM AND POTASSIUM.

The filtrate from the sulphate determination was treated with ammonia and ammonium carbonate and was filtered. The filtrate was evaporated to dryness on the water bath, heated to expel ammonium salts, and digested with a few cubic centimeters of distilled water. Magnesium was precipitated with barium hydrate, the solution was again filtered, and the precipitate was washed with hot water. The filtrate from this operation was heated, and barium and calcium were precipitated with ammonium carbonate and were removed by filtration, after which the filtrate was evaporated to dryness and heated to expel ammonium salts. The residue was digested with 4 or 5 cubic centimeters of water, warmed, and treated again with ammonia and ammonium carbonate to remove traces of barium and calcium. The solution was then filtered into a small porcelain dish and evaporated to dryness. The residue was heated nearly to fusion and weighed. The alkaline chlorides in the dish were dissolved in a little water and were filtered through an ashless filter paper, which was then washed, ignited in the porcelain dish, and weighed. The difference in weights was calculated to "sodium and potassium," the molecular weight 58 being used for the material. The error introduced by disregarding potassium is discussed on page 33. The procedure is similar to that recommended by Fresenius,[b] and it requires no special comment except that care was taken to insure complete removal of impurities. If the third treatment with ammonia and ammonium carbonate produced an appreciable amount of precipitate, the operation was repeated till the last treatment revealed only traces of impurities.

The sodium-potassium ratio of some of the river waters was determined quarterly. The solutions of alkaline chlorides from the ten-day composite samples representing a three months' period were united and repurified in accordance with the procedure just outlined.

[a] Fresenius, C. R., op. cit., vol. 1, 1904, p. 434.
[b] Fresenius, C. R., op. cit., vol. 2, 1905, p. 249.

The pure chlorides were then evaporated nearly to dryness in a Jena dish with sufficient platinic chloride to convert the alkalies into their platinum double salts. The residue was treated with 80 per cent alcohol, and the potassium platinic chloride, removed by filtration through an asbestos mat in a small filter tube, was washed with dilute alcohol, dried in a steam oven, and weighed. By dissolving the potassium platinic chloride in hot water, drying, and again weighing the filter tube, the difference in weight representing the mass of the potassium double salt could be found and computed to parts per million of potassium (K).

CARBONATE AND BICARBONATE RADICLES.

Estimates of the carbonate and bicarbonate radicles were made on the same 50 cubic centimeter sample of the water, which was filtered if necessary. Ten drops of phenolphthalein were added to the measured sample in a porcelain dish of convenient size and the sample was titrated with N/50 potassium acid sulphate solution. The number of cubic centimeters of acid used, multiplied by 24, equals parts per million of the carbonate radicle (CO_3). Two drops of methyl orange were added to the same liquid and the titration was continued. The total amount of acid used, minus twice that required for the first end point, equals that equivalent to the bicarbonates present. The latter figure, expressed in cubic centimeters and multiplied by 24.4, equals parts per million of the bicarbonate radicle (HCO_3). The water was sometimes diluted or a larger amount was taken for titration, but it could not, of course, be concentrated. This procedure is recommended by Cameron [a] and it gave results that are sufficiently satisfactory. The balance between the different forms of carbonic acid in solution is variable, depending largely on concentration, temperature, and pressure. It is fairly certain that many of the waters which gave positive tests for normal carbonates do not contain that form of carbonic acid in nature. It is unjustifiable, however, to assume from the data at hand that no natural stream waters contain normal carbonates, and it is equally impossible definitely to decide which ones do and which ones do not contain them. Consequently the carbonates and bicarbonates are reported exactly as they were determined, but CO_3 has been computed to HCO_3 in calculating the average condition of streams if there were only a few scattered positive tests for normal carbonates. All such recomputations are noted in the tables of analyses, and the figures involved bear the following footnote: "Abnormal; computed as HCO_3 in the average."

[a] Cameron, F. K., Bull. Bur. Soils, U. S. Dept. Agr., No. 64, 1900, p. 63; also Jour. Am. Chem. Soc., vol. 23, 1900, p. 471.

CHLORINE.

The usual volumetric procedure was employed for the determination of chlorine,[a] and the concentrations of solution recommended by Jackson and described by Leighton[b] were used in order that the results might be comparable with normal chlorine determinations. One hundred cubic centimeters of the sample was usually concentrated to 25 cubic centimeters in a porcelain dish on the water bath at a time when hydrochloric acid fumes were not prevalent in the laboratory. If a large amount of the element was present a smaller sample was taken and duplicate determinations were made. After the sample had been concentrated, 1 cubic centimeter of a 5 per cent potassium chromate solution was added and the inside of the dish was thoroughly rubbed down with a rubber policeman. Standard silver nitrate was then added from a burette, till the first faint reddish tint appeared. Each analyst determined by experiment with chlorine-free water the amount of silver nitrate necessary to produce a red coloration detectible by him under regular conditions, and he subtracted that amount from the results of his titrations. The chlorine (Cl) in parts per million was then computed. Samples that were very turbid or highly colored were filtered or were clarified by treatment with alumina cream. When very large amounts of chlorine were present, gravimetric determinations were made by precipitating the chlorine as silver chloride in nitric acid solution, removing the precipitate by filtration through an asbestos mat in a Gooch crucible, drying in a steam oven, and weighing.

NITRATES.

The phenolsulphonic acid method was used for the determination of nitrates.[c] As practically all the surface waters that were tested contained amounts of color sufficient to interfere materially with the color comparison in this test, it was necessary to decolorize the samples before evaporation. A small amount of alumina cream was shaken with 75 to 80 cubic centimeters of the sample in a 4-ounce bottle and allowed to settle, after which 50 cubic centimeters of the clear supernatant liquid was removed either by filtration or by decantation and was evaporated to dryness in a porcelain dish on the water bath with a few drops of sodium carbonate solution. One cubic centimeter of phenolsulphonic acid was quickly and thoroughly rubbed over the residue in the dish, after which 10 cubic centimeters of distilled water was added and the solution was stirred till it was thoroughly mixed. After enough ammonium hydrate to render the

[a] Pub. Health Papers and Reports, Am. Pub. Health Assoc., vol. 30, pt. 2, 1905, p. 66; also Sutton, Francis, A systematic handbook of volumetric analysis, 1904, p. 451.

[b] Leighton, M. O., Field assay of water: Water-Supply Paper U. S. Geol. Survey No. 151, 1905, p. 49.

[c] Public Health Papers and Reports, Am. Pub. Health Assoc., vol. 30, pt. 2, 1905, p. 40.

liquid alkaline had been added, the solution was transferred to a Nessler tube and was diluted to the 100 cubic centimeter mark with distilled water. The yellow color developed by the nitrates was compared with similar shades in Nessler tubes containing solutions of known amounts of potassium nitrate that had been treated with phenolsulphonic acid and ammonia. The results are reported as parts per million of the nitrate radicle (NO_3), not as N, the customary basis in sanitary work. Though this procedure is comparatively accurate for estimating the amount of nitrogen actually present as nitrates at the time of the test, it must be emphatically stated that the reported nitrate figures do not represent the amount of nitrogen present as nitrates in the stream waters when the samples were collected. Practical considerations made it impossible to perform the test less than ten days after some of the samples had been collected and the estimate was made in a great many samples after a period of three to eight weeks, or even more, had elapsed. Inasmuch as this length of time was sufficient for marked changes in the amount of nitrates, the value of the results is problematical. The determination was made in order to complete the estimation of acid radicles that were present in appreciable amount, and though its value as an index of the condition of the stream water at the time the samples were taken is probably not great, the comparative amounts in the different streams may furnish some information regarding the amount of organic matter that is present, and this feature is the excuse for the presentation of the nitrate figures in the analytical data.

TOTAL ACIDITY.

If the water under examination contained free mineral acid a convenient amount of the sample, filtered if necessary, was titrated with N/10 sodium carbonate in the presence of methyl orange indicator. If 50 cubic centimeters of water is titrated, the number of cubic centimeters of N/10 alkali used, multiplied by 98, gives the result in parts per million of free sulphuric acid (H_2SO_4).

TOTAL IRON.

As most of the iron in many river waters forms part of the suspended matter rather than part of the matter in solution, a figure representing to some extent the total amount of iron was estimated at some laboratories. The test was made by boiling vigorously 50 cubic centimeters of the unfiltered sample ten or fifteen minutes with 1 cubic centimeter each of concentrated nitric and hydrochloric acids. The liquid was then filtered, and the iron in it was determined colorimetrically by the sulphocyanide method. The figure obtained in this manner is only approximate, as all the iron in the suspended matter is probably not dissolved by this treatment.

PREPARATION OF SOLUTIONS.

TWENTIETH-NORMAL POTASSIUM PERMANGANATE.

About 2 grams of potassium permanganate crystals were dissolved in freshly boiled distilled water, and the solution was filtered through glass wool and diluted to 1 liter. The strength of the solution was determined by titration against iron. Three portions of pure iron wire, each weighing about 0.2 gram, were dissolved in 125 cubic centimeter Erlenmeyer flasks in 40 cubic centimeters of water and 10 cubic centimeters of concentrated sulphuric acid. The solutions were cooled rapidly to about 60° C. and diluted to 50 cubic centimeters with freshly boiled distilled water. One portion was titrated with the permanganate solution, which was then diluted to one-twentieth normal strength, and the other two portions were used to verify the accuracy of the dilution. The amount of permanganate necessary to produce a detectible red coloration with 10 cubic centimeters of concentrated sulphuric acid and 40 cubic centimeters of water was subtracted from each titration, and the iron wire was considered to be 99.6 per cent pure Fe. The strength of the permanganate solution was verified in many tests also by titration against potassium tetraoxalate and against Iceland spar. One cubic centimeter of N/20 potassium permanganate is equivalent to 0.001 gram of calcium (Ca) from calcium oxalate.

AMMONIUM ACETATE.

Forty-four cubic centimeters of ammonium hydrate (specific gravity 0.90) and 37 cubic centimeters of glacial acetic acid were dissolved in 1 liter of distilled water.

STANDARD SODIUM AMMONIUM PHOSPHATE SOLUTION.

In 1 liter of distilled water 8.4507 grams of sodium ammonium phosphate was dissolved. One cubic centimeter of this solution should be equivalent to 0.001 gram of magnesium (Mg), and the strength was always verified by gravimetric determination of the phosphate radicle.

STANDARD URANIUM SOLUTION.

About 21 grams of uranium nitrate was dissolved in 800 cubic centimeters of distilled water, enough ammonium hydrate to produce a slight turbidity was added, then 50 grams of glacial acetic acid was added, and the whole was diluted to 1 liter with distilled water. Ten cubic centimeters of the solution of sodium ammonium phosphate was next mixed in a beaker with 5 cubic centimeters of ammonium acetate and 35 cubic centimeters of distilled water. After this

solution had been heated to boiling the uranium solution was added till the faintest brown coloration appeared, when a drop of the liquid was mixed with a drop of half-saturated solution of potassium ferrocyanide on a white porcelain slip. As soon as the coloration appeared the solution was diluted to 50 cubic centimeters with boiling water and the test was repeated. If the operation had been properly conducted no red coloration appeared in the second test, and the addition of two or three drops of uranium solution was necessary before the final reading. The amount of uranium solution necessary to produce a detectible red coloration in a blank test was subtracted from all titrations. The uranium solution was then diluted till 1 cubic centimeter of it was exactly equivalent to 1 cubic centimeter of the solution of sodium ammonium phosphate, and the accuracy of the dilution was verified by additional titrations against sodium ammonium phosphate.

METHYL ORANGE.

One gram of methyl orange was dissolved in 1 liter of distilled water and the solution was filtered. As the accuracy of the bicarbonate estimate depends largely on the quality of the indicator, special care was taken to select a satisfactory article. Several samples of methyl orange were tested, and the one that gave the most satisfactory results was used exclusively for the estimates.

PHENOLPHTHALEIN.

Ten grams of phenolphthalein was dissolved in 500 cubic centimeters of alcohol (specific gravity 0.834), and the solution was diluted to 1 liter with distilled water.

FIFTIETH-NORMAL POTASSIUM ACID SULPHATE.

About 3 grams of potassium acid sulphate was dissolved in 1 liter of freshly boiled distilled water. A portion of the solution was titrated against some other carefully standardized solution, using methyl orange indicator, and the strong solution was then diluted to one-fiftieth normal strength with distilled water. Normal sulphuric acid, which had been tested both by titration against alkali and by precipitation with barium chloride, was usually employed as a basis for standardization.

POTASSIUM CHROMATE SOLUTION.

The solution of potassium chromate was prepared by dissolving 50 grams of the pure salt in 1 liter of distilled water and then adding sufficient silver nitrate to precipitate all the chlorine present and turn the solution slightly reddish. This was allowed to stand, and the clear solution was then obtained by filtering or decanting.

STANDARD SALT SOLUTION.

A solution containing 0.001 gram of chlorine in each cubic centimeter was made by dissolving 1.648 grams of fused sodium chloride in 1 liter of distilled water free from chlorine.

STANDARD SILVER SOLUTION.

In 1 liter of distilled water free from chlorine was dissolved $2\frac{1}{2}$ grams of crystallized silver nitrate. Water or strong silver nitrate was added to this solution until by actual titration 10 cubic centimeters of it was equivalent to 5 cubic centimeters of the standard salt solution. One cubic centimeter of the solution of silver nitrate was then equivalent to 0.0005 gram of chlorine.

STANDARD NITRATE SOLUTION.

In 1 liter of distilled water was dissolved 1.63 grams of potassium nitrate. One cubic centimeter of this solution contains 0.001 gram of NO_3. Fifty cubic centimeters of this strong solution was cautiously evaporated to dryness on the water bath, and the residue was moistened equally and thoroughly with 2 cubic centimeters of phenolsulphonic acid and was diluted to 1 liter with distilled water. One cubic centimeter of this solution contains 0.00005 gram of NO_3. The necessary amounts of this solution, which was used as a standard, were made alkaline with ammonia as needed and were diluted in Nessler tubes to 100 cubic centimeters with distilled water.

PHENOLSULPHONIC ACID.

Seventy-five grams of pure melted phenol was added slowly with constant agitation to 925 grams of sulphuric acid (specific gravity 1.84) in a liter flask. The flask, covered with a watch glass, was then heated on a water bath for six hours to insure complete sulphonation of its contents.

TENTH-NORMAL SODIUM CARBONATE.

A strong solution of the purest crystallized sodium carbonate that could be obtained was titrated against normal sulphuric acid and diluted to one-tenth normal strength, which was verified also by titration against N/50 potassium acid sulphate. One cubic centimeter of N/10 sodium carbonate is equivalent to 0.0049 gram of sulphuric acid.

DEPARTURES FROM REGULAR PROCEDURES.

GENERAL DEPARTURES.

The regular procedures were followed systematically in most of the analytical work, the only exceptions being in some matters of minor detail. Calcium and magnesium were estimated gravimetrically for short periods at some of the laboratories, and the amount of water used for the different determinations, especially for suspended solids, was changed at will in order to obtain the best working conditions.

ANALYSES OF MISSISSIPPI RIVER.

The daily samples of water from Mississippi River at New Orleans were united in sets of seven instead of ten. The most important departure in analysis of the composites was in regard to suspended solids, from which the water was freed by filtering it with suction through Berkefeld filter tubes; the effect of passing the water of Mississippi River through these stones was practically negligible so far as the mineral content was concerned, because large quantities of water were available. The residue from evaporating 100 cubic centimeters of the filtered water was dried at 110° C. instead of 180° C. and was weighed for total dissolved solids. Silica, oxides of iron and aluminum, calcium, and magnesium were determined gravimetrically on the residue from 2 liters of water, and from 2 to 4 liters was taken for estimation of sulphates and the alkalies.

ANALYSES OF ANDROSCOGGIN RIVER.

Spot samples were collected weekly from Androscoggin River, and the small amount of mineral matter in the water necessitated several refinements in method. The water was nearly free from suspended matter except flocculent particles, from which a clear liquid was decanted after sedimentation. Three liters of the clear water was evaporated to dryness, and the residue was dried below red heat till it became white, before it was weighed. It was then treated with hydrochloric acid; and silica, oxides of iron and aluminum, and calcium were determined gravimetrically. One-half the filtrate was used for gravimetric estimate of magnesium and the other half for gravimetric estimate of sulphates and alkalies. Sodium and potassium were separated by treatment with platinic chloride. The carbonate and bicarbonate radicles were not estimated; consequently no values have been reported for them. The amount of bicarbonates equivalent to the average excess of the bases over sulphates and chlorine in this water is 20 parts per million, which, added to the sum of the dissolved constituents that were estimated, gives 48 parts per million. The latter figure is probably more nearly comparable with

the figures representing total dissolved solids at 180° C. than the average of the determinations of the residue reported on page 48.

ANALYSES OF SOUTHERN RIVERS.

Some river waters of the Southeastern States are characterized at certain seasons of the year by suspended matter so finely divided that ordinary methods of filtration fail to remove it, and as a consequence much trouble was experienced in obtaining a clear filtrate for determination of the dissolved constituents. The difficulty was finally overcome by treatment with aluminum hydrate as described on page 14, but between November, 1906, and June, 1907, the procedure in the following paragraph was used for waters of this character.

A convenient amount of the samples was filtered through an asbestos mat in a Gooch crucible for the determination of suspended matter, and the filtrate, clarified later if necessary, was used for estimation of nitrates, chlorine, carbonates, and bicarbonates. A much clearer liquid was obtained by filtering 750 cubic centimeters of the sample through a mat of ashless paper pulp in a Gooch crucible, and the amount of suspended iron in the residue on the mat was determined volumetrically. Two-thirds of the filtrate was evaporated to dryness in acid solution in a porcelain dish, and the residue was used for estimation of silica, iron, calcium, and magnesium. One-third of the filtrate was evaporated to dryness without acid in a platinum dish, and the residue was dried and weighed for determination of dissolved solids, after which it was used for estimation of sulphates and alkalies.

PROBABLE ACCURACY OF ESTIMATES.

THEORETICAL LIMITS OF ACCURACY.

The theoretical limits of accuracy in the procedures have been estimated by consideration of the amounts of water used for the determinations, the probable accuracy of the balances, burettes, and standard solutions that were employed, the impurities in the reagents, and the manipulative errors to which the results were subject. Such estimates of accuracy, apart from some influences that may be computed mathematically, are more or less approximate, because the magnitude of the errors may perhaps be decreased by practicing, or increased by failing to practice, certain refinements in the analytical methods; but they are introduced for the purpose of showing the number of figures that may be significant in the results. The probable limits of accuracy are given in Table 3, in which the first column gives the name of the determination, the second column the amount of water usually taken, and the third column the theoretical minimum amount that can be estimated with any precision when the constituent is present in comparatively small amount. The minimum of accurate estimate increases with the actual mass of the substance.

TABLE 3.—*Limits of accuracy of the determinations.*

Name of determination.	Amount of water usually taken.	Minimum limit of accuracy.	Name of determination.	Amount of water usually taken.	Minimum limit of accuracy.
Turbidity		3	Sodium and potassium (Na+K)	250	0.5
Suspended matter	500	1	Carbonate radicle (CO_3)	50	2.5
Total solids	500	1	Bicarbonate radicle (HCO_3)	50	2.5
Silica (SiO_2)	500	.6	Sulphate radicle (SO_4)	250	.5
Iron (Fe)	500	.05	Chlorine (Cl)	100	.5
Calcium (Ca)	250	.8	Nitrate radicle (NO_3)	50	.09
Magnesium (Mg)	250	.8			

The assigned limits of accuracy probably err by being too small instead of too large. The way in which they were evolved may be illustrated by the determination of calcium. In the regular procedure the calcium in 250 cubic centimeters of the sample is precipitated with ammonium oxalate in alkaline solution, heated, removed by filtration, dissolved in sulphuric acid, and titrated with N/20 potassium permanganate. The estimate is subject to certain errors, among which may be mentioned errors in measuring the amount of water to be used, in standardizing the permanganate solution, and in measuring the permanganate solution; errors due to the use of an improper end point, to organic matter from the filter paper, to organic matter in the sample, and to oxalic acid retained by the paper or occluded by the precipitate; and errors due to solubility of calcium oxalate in the precipitating solution and to retention of other oxalates in the precipitate. An error of 0.1 cubic centimeter in measuring 10 or 20 cubic centimeters of permanganate solution, which is not unlikely, would be equivalent to 0.4 part per million of calcium for a 250 cubic centimeter sample. The filter paper may contribute oxidizing matter equivalent to an amount of permanganate between 0.03 and 0.10 cubic centimeter, averaging 0.08 cubic centimeter, or 0.32 part per million of calcium. It would be surprising, indeed, if the addition of the positive and negative errors due to other sources of inaccuracy did not contribute an error equivalent to 0.08 part per million. Consequently the estimate of calcium in 250 cubic centimeters of water should not be considered accurate within 0.8 part per million when ordinary amounts of the substance are present, and it would probably be in greater error when large amounts of calcium are present or when smaller amounts of water are used for the determination.

It is probable that some of the analytical results are subject to even greater inaccuracy. The estimates in the third column of Table 3 are, however, given more for the purpose of demonstrating the limit to which reliance should be placed on the analyses than for any other purpose, and this consideration of the probable accuracy of the estimates leads to the interesting subject of the number of figures that

may be considered significant in the results. The committee on standard methods of water analysis of the American Public Health Association[a] has recommended that when the results show quantities above 10 parts per million no decimals be reported; that when results are between 1 and 10 parts one decimal only should be reported, and that when results are between 0.1 and 1 part two decimals only should be reported. These rules, though they were suggested especially for sanitary work, have much merit when applied to all water analyses; and if they were generally adopted these limitations would render unnecessary much unjustifiable figuring and would still leave results sufficiently accurate for all practical purposes. The recommendations of the committee were adopted in the present investigation, and though they do not coincide exactly in all respects with the minimum limits of accuracy recorded in Table 3, it was thought best to follow them rigidly rather than to attempt to adjust the results of each determination to an estimate that depends more or less on judgment rather than on accurate determination by analytical methods.

COMPARISON OF THE SUM AND TOTAL SOLIDS.

The probable accuracy of the analyses can be checked by comparing the sum of the constituents with the figure for total solids and by comparing the combining weights with the acids and the bases with each other. The first comparison shows the advantage of drying the total residue at 180° C. Some organic matter is left in the residue at that temperature, depending largely on its nature, and a little water sometimes remains. Part of the carbonates are probably decomposed, especially if much silica is present, and all the half-bound carbonic acid is volatilized. If much magnesium chloride is formed in the residue, part of the chlorine probably escapes. Usually, however, these sources of error tend to neutralize one another, and a fairly good agreement is found between total solids and the sum of the dissolved constituents minus the half-bound carbonic acid. In order to illustrate this point, 800 analyses made at one laboratory by several chemists have been grouped according to the magnitude of the figure representing total dissolved solids, and the average difference between the sum of the constituents and this total has been computed for each group. The results are tabulated below. The last two lines of this table have been supplied from work done at another laboratory because the determinations of high solids at the first laboratory were not sufficiently numerous to justify computation of averages.

[a] Public Health Papers and Reports, Am. Pub. Health Assoc., vol. 30, pt. 2, 1905, p. 26.

TABLE 4.—*Average difference between dissolved solids and the sum of the constituents.*

[Parts per million.]

Dissolved solids.		Average difference (plus or minus).
Not less than—	Less than —	
.....	50	4
50	100	5
100	200	5
200	300	6
300	400	9
400	1,000	25
1,000	.....	60

The figure for total solids is the higher in more than 90 per cent of the analyses, a condition showing the presence of organic matter and undetermined constituents. Ten parts excess of total solids is not uncommon, especially in highly colored waters, but 10 parts excess of the sum of the constituents is unusual in waters running below 200 parts per million of solids, and results of that character should be carefully examined for error. The excess of total solids over the sum of the constituents may be 10 to 15 parts in a sample containing 100 to 200 parts per million of solids, if much organic matter is present; it may be higher in highly sulphated or chlorinated waters, especially with a high sodium base, but it does not usually exceed 10 to 15 parts in ordinary carbonated waters, even in those containing as much as 300 parts of total solids.

The average differences between total solids and the sum of constituents in analyses of waters that had been treated with aluminum hydrate as described on page 14 were somewhat less than the differences on untreated waters from rivers containing water of similar character, and excesses of the sum over the total solids were somewhat more common. Inasmuch as the waters treated in this manner were high in organic matter, most of which was removed by the aluminum hydrate, the facts just detailed seem to corroborate the belief that much of the difference between total solids and the sum is due to organic matter; but the evidence on this point is not conclusive.

ERROR OF COMBINING VALUES.

METHODS OF COMPUTATION.

The accuracy of the analyses was also checked by comparing the combining weights of the acidic and the basic radicles with each other. The constituents ordinarily present in natural waters in appreciable amount were quantitatively determined by analysis; therefore, the difference between the sum of the combining weights of the acidic radicles and the sum of the combining weights of the

basic radicles is a good test of the accuracy of the analysis. Each radicle expressed in parts per million was multiplied by its valence and the product divided by its molecular weight. The quotient is the combining weight of the radicle in parts per million; or to prevent confusion it may be called the combining value. The difference between the sum of the acidic and the sum of the basic values, multiplied by 100, then divided by the sum of all the values, represents the percentage of error of the combining values. Factors for computing the combining value from the amount of the radicle are given in Table 5.

TABLE 5.—*Factors for computing combining values.*

	Factor.		Factor.		Factor.
Iron (Fe)	0.0358	Potassium (K)	0.0255	Sulphate radicle (SO_4)	0.0208
Aluminum (Al)	.1107	Carbonate radicle (CO_3)	.0333	Nitrate radicle (NO_3)	.0161
Calcium (Ca)	.0499	Bicarbonate radicle (HCO_3)	.0164	Chlorine (Cl)	.0282
Magnesium (Mg)	.0821				
Sodium (Na)	.0434				

The method of computation is illustrated in Table 6, in which the calculations are made on an analysis of Susquehanna River.

TABLE 6.—*Illustration of methods of computing probable accuracy of analysis.*

I. Analytical statement.	Parts per million.	II. Computation of error.	Parts per million.	Factor.	Combining value.
Silica (SiO_2)	9.0				
Iron (Fe)	.05				
		Bases:			
Calcium (Ca)	26	Calcium (Ca)	26	× 0.0499	=1.30
Magnesium (Mg)	6.4	Magnesium (Mg)	6.4	× .0821	= .52
Sodium and potassium (Na+K).	12	Sodium and potassium (Na+K).	12	× .0434	= .52
					2.34
		Acids:			
Carbonate radicle (CO_3)	32.0	Carbonate radicle (CO_3)	0.0	× 0.0333	=0.00
Bicarbonate radicle (HCO_3) 66; equivalent amount of CO_3.		Bicarbonate radicle (HCO_3).	66	× .0164	=1.08
Sulphate radicle (SO_4)	42	Sulphate radicle (SO_4)	42	× .0208	= .87
Chlorine (Cl)	9.8	Chlorine (Cl)	9.8	× .0282	= .28
Nitrate radicle (NO_3)	7.0	Nitrate radicle (NO_3)	7.0	× .0161	= .11
					2.34
Sum of constituents	144				
Total solids	142	Percentage of error	$\frac{100(2.34 - 2.34)}{2.34 + 2.34}$		=0.0
Difference	+2				

Silica has been considered to be present in colloidal form, and this is in accordance with the generally accepted view. Kahlenberg and Lincoln,[a] who are quoted by Clarke,[b] conclude from their experiments that it appears safe to say that in natural waters silica always

[a] Kahlenberg, L., and Lincoln, A. T., Solutions of silicates of the alkalies: Jour. Phys. Chem., vol. 2, 1898, p. 77.

[b] Clarke, F. W., The data of geochemistry: Bull. U. S. Geol. Survey No. 330, 1898, p. 151.

occurs in the colloidal state, and Kohlrausch[a] and other investigators make practically the same statement. Iron and aluminum have been treated as bases in waters containing free mineral acids and as if present in colloidal state in all other waters. The omission or addition of iron in the bases makes no practical difference in the calculated error of nearly all the analyses, and aluminum was usually not estimated.

Sodium and potassium have been computed as if no potassium were present—that is, the alkalies have been computed from the weight of the combined chlorides by using the molecular weight 58. That this disregard of potassium in analyses of ordinary river waters introduces a negligible error may be demonstrated mathematically as follows. The ratio of sodium to potassium determined on 103 composite samples of river water is between 1.8 and 31.2, averaging 5.1, and the assumption that the ratio equals 2 allows practically a maximum value for potassium. If Na/K = 2, the error expressed in percentage of the calculated combining value of the alkalies is given in the following equation, in which x equals the amount of potassium in parts per million:

$$\frac{39.4\times0.0434(2.54\times2x+1.90x)-4.34\times2x-2.55x}{0.394\times0.0434(2.54\times2x+1.90x)}=5.9$$

If it is assumed that Na/K equals 5 the error is 2.8 per cent of the combining value of the alkalies. Furthermore, as high alkalies are usually accompanied by high ratios, it is doubtful whether a river with sodium and potassium as high as 15 per cent of the combining values would have a ratio as low as 5. In fact, the assumptions that the combining value of Na + K equals 18 per cent of the total combining weights and that the ratio Na/K equals 2 probably represent extreme and very unusual conditions, and even under such conditions the error introduced by using the molecular weight of sodium chloride is only 1 per cent.

On the other hand, the calculation of potassium as such when the true ratio is known increases the sum of the constituents. If x equals the ratio Na/K the ratio of the true value of Na + K to the calculated value of Na + K becomes

$$\frac{x+1}{x+0.75}.$$

In other words, the calculated value for sodium and potassium is always less than the true value, and the difference between the two is greater as x decreases. But this error also is negligible in nearly all analyses. Other elements either not included in the estimates

[a] Kohlrausch, F., Über Lösungen von Natriumsilikaten: Zeitschr. physikal. Chemie, vol. 12, 1893, p. 773.

or disregarded in the computations, such as barium, strontium, lithium, manganese, and phosphates, are probably present in quantities so small that they have no appreciable effect on the calculations. Organic acids, which were not estimated, are an important exception to this statement, and they probably account for many of the computed excesses of bases over acids.

An important feature to be considered in discussing the probable accuracy of the analyses is the limit of accuracy of the individual determinations. The specimen analysis in Table 6 has 142 parts per million of total solids and the computed percentage of error of the combining values is zero. If, however, each radicle were in error by the amount given in Table 2 as the limit of accuracy in determination an error of 4 per cent would accrue; but as this theoretica-maximum error is based on the assumption that eight figures may attain the maximum deviation in a given direction in the same analysis, the probabilities of its occurrence are small. When the error of combining values is as high as this or higher it is usually the case that one or two constituents deviate by an amount more than the theoretical limit of accuracy while the other radicles are relatively constant. The percentage of error due to this source varies inversely with the sum of the constituents; in other words, it is greater with low total solids and less with high total solids. It also changes somewhat with changes in the relative composition of the residue. It is interesting to note in this connection that the computations of 800 analyses made at one laboratory give 3.9 per cent as the average error of the combining values, with an average of total solids of 130 parts per million, figures coinciding almost exactly with the theoretical estimates.

RELATION BETWEEN TOTAL SOLIDS AND PERCENTAGE OF ERROR.

Though part of the analyses made in accordance with the regular methods are reported in this paper only by averages, it is deemed proper to discuss the errors of all in this section because of the amount of available material. The analyses, irrespective of the source from which the waters were taken and the laboratory in which the analyses were made, have been grouped according to the amount of total solids, and the percentages of error of the combining values have been averaged by groups. The results of these computations are presented in Table 7. Practically all the analyses were made with the regular amounts of water, and those in which greater or less amounts were used are so few that they do not affect the results.

TABLE 7.—*Percentage of errors of combining values grouped according to the amount of dissolved solids.*

Dissolved solids (parts per million).		Number of analyses.	Average error of combining weights (per cent).
Not less than—	Less than—		
.....	50	65	6.5
50	100	844	5.3
100	200	713	4.5
200	300	907	3.1
300	400	451	2.9
400	500	137	2.8
500	1,000	134	2.6
1,000	2,000	70	1.6
		3,321	

The average error computed for the entire number of 3,321 analyses is 3.9 per cent, with an average of dissolved solids of 230 parts per million. The average errors of the several groups range from 6.5 per cent for solids below 50 parts to 1.6 per cent for solids between 1,000 and 2,000 parts per million, and the magnitude of the error decreases with increase of dissolved solids. A comparatively small number of very large errors make the averages somewhat higher than they otherwise would be, nearly two-thirds of the analyses having errors smaller than the averages of their respective groups. In 60 per cent of the analyses the bases are in excess, but this preponderance of positive errors is confined almost entirely to waters in which the dissolved solids are less than 250 parts per million and is not great enough to be especially significant. The significance of the average error of 3.9 per cent with 230 parts per million of dissolved solids can better be realized when it is considered that if it were all concentrated in a single determination it would amount to only 14 parts of bicarbonates, 5 parts of calcium, or 3 parts of magnesium. It corresponds to an average error in the individual determination of about 4 per cent, which is far within the limits of ordinary practice. In consideration of the relatively small amounts of substance that may cause these errors, it may be concluded that the procedures are sufficiently accurate for the practical analysis of waters for purposes of geologic and industrial interpretation.

As the procedures were used in several laboratories, an opportunity is afforded for observing their general availability in the hands of different chemists. The average percentage errors for several analysts were between 3.2 and 5.3 per cent. These figures are complicated by the fact that the difference in quality of the waters at various laboratories affected somewhat the accuracy of the determinations; nevertheless the highest average error coincides with the lowest

average of total solids, and the lowest average error with the highest average of total solids; in other words, the errors of analysis of different chemists follow nearly the same order shown in Table 7, and depend more on the quality of the water than on the personal equation of the analyst.

RELATION BETWEEN SOURCE AND PERCENTAGE OF ERROR.

After the analyses had been tabulated by rivers, the average percentage of error of the individual analyses of water from each river was computed. Then, by applying the criteria for rejecting estimates (see p. 38), abnormal figures in the analyses were detected and omitted from the tabulations, and the remaining figures in each set were averaged in order to show the average condition of the waters, the average percentage error of the individual analyses, the percentage of error of the averages, and the average total dissolved solids of each river. The plus signs in the last column of the following table indicate that the bases are in excess, and the minus signs indicate that the acidic radicles are in excess:

TABLE 8.—*Average percentage of errors of combining weights.*

Source (river, except as noted).	Sampling station.	Average total dissolved solids (parts per million).	Average percentage of error of individual analyses.	Percentage of error of average.
Brazos	Waco, Tex	1,136	2.1	− 0.6
Wabash	Logansport, Ind	807	2.2	− 2.5
Arkansas	Little Rock, Ark	630	2.1	− 0.2
Red	Shreveport, La	561	2.1	+ 1.8
Minnesota	Shakopee, Minn	480	3.4	− 0.3
Missouri	Florence, Nebr	454	2.8	− 0.7
White	Indianapolis, Ind	450	2.1	− 0.8
Platte	Columbus, Nebr	437	2.9	+ 0.6
Missouri	Kansas City, Kans	426	3.9	− 0.4
Missouri	Ruegg, Mo	346	3.6	− 0.1
Wabash	Vincennes, Ind	336	3.3	− 0.8
Des Moines	Keosauqua, Iowa	312	3.1	+ 1.3
Platte	Fremont, Nebr	302	2.6	+ 0.5
Maumee	Toledo, Ohio	298	2.3	+ 0.8
North Platte	North Platte, Nebr	294	2.6	+ 1.9
Miami	Dayton, Ohio	289	1.5	+ 0.2
White	Azalia, Ind	279	3.4	+ 0.1
Grand	Grand Rapids, Mich	258	1.7	+ 0.4
Iowa	Iowa City, Iowa	247	3.1	+ 1.4
Muskingum	Zanesville, Ohio	244	3.9	− 0.6
Kalamazoo	Kalamazoo, Mich	242	3.6	+ 1.9
Cedar	Cedar Rapids, Iowa	228	3.2	+ 0.3
Mississippi	Memphis, Tenn	202	4.9	+ 4.6
Mississippi	Minneapolis, Minn	200	4.1	+ 1.0
Youghiogheny	McKeesport, Pa	197	4.5	+ 1.6
Mississippi	New Orleans, La	166		+ 4.0
Shenandoah	Millville, W. Va	140	3.2	+ 2.1
St. Lawrence	Ogdensburg, N. Y	[a] 134	1.1	− 1.2
Lake Erie	Buffalo, N. Y	[a] 133	1.4	− 0.8
Potomac	Cumberland, Md	130	4.2	− 0.5
Cumberland	Kuttawa, Ky	124	4.5	+ 2.7
Tennessee	Knoxville, Tenn	122	4.7	− 0.3
Cumberland	Nashville, Tenn	119	5.0	+ 3.6
Lake Michigan	St. Ignace, Mich	[a] 118	0.9	+ 0.2
Susquehanna	Danville, Pa	112	3.9	+ 0.3
Hudson	Hudson, N. Y	108	3.0	+ 1.4
Lake Huron	Port Huron, Mich	[a] 108	1.7	+ 1.5
Kentucky	Frankfort, Ky	104	4.5	+ 3.0
Tennessee	Gilbertsville, Ky	101	6.4	+ 3.5

[a] Double portions of water used for analysis.

TABLE 8.—*Average percentage of errors of combining weights*—Continued.

Source (river, except as noted).	Sampling station.	Average total dissolved solids (parts per million).	Average percentage of error of individual analyses.	Percentage of error of average.
Wisconsin	Portage, Wis	98	9.8	+ 8.1
Lehigh	South Bethlehem, Pa	95	3.6	+ 1.0
Tombigbee	Epes, Ala	94	5.3	+ 5.7
Chippewa	Eau Claire, Wis	90	11.8	+10.0
Susquehanna	West Pittston, Pa	90	4.3	− 0.3
James	Richmond, Va	89	3.7	+ 0.4
Allegheny	Kittanning, Pa	87	2.5	+ 2.1
Raritan	Bound Brook, N. J	85	4.0	+ 2.0
Alabama	Selma, Ala	82	7.3	+ 6.3
Oostanaula	Rome, Ga	82	4.5	+ 9.0
Monongahela	Elizabeth, Pa	81	4.5	− 0.4
Roanoke	Randolph, Va	79	3.5	− 0.4
Oswegatchie	Ogdensburg, N. Y	77	7.2	+ 4.9
Cahaba	Birmingham, Ala	76	6.2	+ 6.0
Susquehanna	Williamsport, Pa	74	5.7	+ 0.9
Wateree	Camden, S. C	73	4.8	+ 5.1
Neuse	Raleigh, N. C	73	4.7	+ 1.0
Dan	South Boston, Va	71	4.0	− 1.4
Delaware	Lambertville, N. J	70	5.5	+ 0.4
Ocmulgee	Macon, Ga	69	5.0	+ 8.5
Pedee	Pee Dee, N. C	69	3.4	+ 9.1
Oconee	Dublin, Ga	68	5.0	+ 3.9
Flint	Albany, Ga	67	6.9	.....
Saluda	Columbia, S. C	62	5.1	.....
Savannah	Augusta, Ga	60	6.6	+11.7
Lake Superior	Sault Ste. Marie, Mich	[a] 60	2.0	+ 1.5
Pearl	Jackson, Miss	59	3.6	+ 4.4
Cape Fear	Wilmington, Del	57	4.4	+ 3.0
Chattahoochee	West Point, Ga	52	5.8	+ 8.5
Androscoggin	Brunswick, Me	48	.....	.....

[a] Double portions of water used for analysis.

The average percentage of error of the combining values in the individual analyses increases inversely with the total solids, with few exceptions, as might be anticipated from the results in Table 7. The percentages of error of the averages do not bear any fixed relation to the percentages of error of the individual analyses, except that the former are usually smaller. This decrease is due partly to the elimination of abnormal estimates before computing the averages, but calculation of averages without omitting any figures has proved that only a small part of the decrease is due to that factor, and it is reasonable to conclude, therefore, that a portion of the error is variable. A considerable part of the difference between the error of the average and the error of the individual analyses is caused apparently by variable manipulative errors that tend to neutralize each other in the average. A few of the rivers, notably the Oswegatchie at Ogdensburg, N. Y., the Delaware at Lambertville, N. J., the Chippewa at Eau Claire, Wis., and the Wisconsin at Portage, Wis., have high percentages of error of the individual analyses, and all except Delaware River have high positive errors in the averages. The errors of nearly all the analyses of water from these four rivers are positive; that is, the bases are higher than the acids. It is significant that all

these rivers are high in organic matter of vegetable origin, and possibly organic acids are present in equilibrium with a portion of the bases.

RELATION BETWEEN AMOUNT OF WATER AND PERCENTAGE OF ERROR.

Regular amounts of water for the individual determinations were used in most of the analyses that have been discussed. Double the regular amounts were, however, used in the analyses of 60 waters from the Great Lakes and from St. Lawrence River, and half the regular amounts were used for 600 waters, the errors of which are not included in Tables 6 and 7. The average percentage of error of combining values of the lake waters is 1.4 per cent, and the average of dissolved solids is 111 parts per million. The same figures for analyses made with the usual amounts of water are 3.7 and 230, respectively, and the corresponding averages for analyses made with half the regular amounts of water are 5.3 and 650. Though the lakes contain very clear carbonated waters with little organic matter in them and the waters in the last set are high in fine, gummy suspended matter which complicates the analysis, yet the figures just given indicate a relation between the amount of water that is used and the percentage of error of the analysis, thus giving additional evidence in favor of the conclusion that the errors have a large variable proportion. General experience in the laboratory has shown that it is better to use double portions of water when dissolved solids are less than 70 parts per million and to run duplicate determinations with smaller amounts of water when dissolved solids exceed 600 parts per million.

REJECTION OF ANALYSES.

Table 9 shows the bases on which analyses or parts of analyses were rejected. The limits have been fixed in accordance with theoretical computations and experience gained in practical work.

TABLE 9.—*Criteria for rejecting analytical data.*

Parts per million.				Per cent.
Dissolved solids.		Maximum excess of total dissolved solids over sum of constituents.	Maximum excess of sum of constituents over total dissolved solids.	Maximum error of combining values.
Not less than—	Less than—			
.....	50	15	5	15
50	100	20	6	7
100	200	30	8	5
200	500	40	12	4
500	1,000	50	.....	3
1,000	2,000	.....	.....	2

Analyses exceeding these limits should be subjected to careful scrutiny, and doubtful estimates should be either repeated or rejected. Due allowance should be made for organic matter that may be present, and an excess of the sum of the constituents over dissolved solids should be more carefully scrutinized than the opposite condition.

METHOD OF EXPRESSING ANALYTICAL RESULTS.

STATEMENT IN PARTS PER MILLION.

The results of the analyses in this paper are stated in parts per million, and though the amounts of water for examination were measured by volume the mineralization is usually so low that the figures may be considered to represent parts per million by weight. Simplicity of computations, avoidance of fractions, and certainty of the basic unit make this decimal system especially satisfactory for practical purposes. Expression of the results of water analyses in parts per million has been generally adopted by sanitary and research chemists and by many technical chemists, and the exclusive employment of this unit industrially is delayed only by more or less objectionable precedent.

For the convenience of those who may desire to transfer the results in this volume to other forms of expression it may be stated that an amount in parts per million multiplied by 0.058 gives the equivalent in grains per United States gallon of 231 cubic inches; multiplied by 0.07 gives the equivalent in grains per imperial gallon, and multiplied by 0.00833 gives the equivalent in pounds per thousand gallons.

STATEMENT IN IONIC FORM.

The analytical methods commonly applied to the examination of water permit the estimation of the elements and radicles that are present. They also enable the determination of the total amount of mineral matter in solution, and by the treatment with dilute alcohol employed by Dudley,[a] the Kennicott Water Softener Company,[b] and others they allow more or less approximate separation of the incrusting from the nonincrusting constituents. But, further than this, ordinary chemical tests contribute little to knowledge regarding the chemical composition of mineral waters, and consequently the exact amounts of the different salts in solution are largely matters of conjecture. In an ordinary mineral water, for instance, it is customary to determine by analysis the amounts of the several ingredients—silica, iron, aluminum, calcium, magnesium, sodium,

[a] Personal communication from Dr C. B. Dudley, chief chemist, Pennsylvania Lines.

[b] Method of water analysis, published by the Kennicott Water Softener Company, Chicago Heights, Ill.

potassium, the carbonate, bicarbonate, sulphate, and nitrate radicles, chlorine, and other bases and acids that it may be desirable to estimate; but the salts like sodium chloride, potassium carbonate, or magnesium sulphate are not determined as such, and though salts are probably present in solution the analytical data are insufficient to permit the apportionment of the bases among the acids.

According to the dissociation theory advanced by Arrhenius and supported by the exhaustive researches of physical chemistry, a salt in solution becomes more or less thoroughly ionized, and its ingredients exist not only in molecular condition but also in the ionic state, the extent of dissociation being dependent on the nature of the salt and on other factors. All the bases present are in equilibrium, more or less, with all the acids, but with information only as to the amount of the elements and radicles that are in a natural water it becomes mathematically impossible to calculate the correct amounts of the different salts in solution. Yet many water analysts have been accustomed to make such combinations in accordance with rules that may appear reasonable or advisable at the time. As such rules are necessarily arbitrary in their nature, however, reports by different analysts are frequently so widely divergent in form as to be incapable of comparison with each other. As Clarke[a] has so aptly stated it, "The result is a meaningless chaos of assumptions and uncertainties." Reference to directions given by various authors[b] shows the divergence of practice in uniting the bases and acids when combinations are computed, and it suggests the complications that occur in practice. Handy[c] has called particular attention to the confusion in methods of computation, and McGill,[d] Kimberley,[e] and others also mention it.

There is at present a well-defined desire among chemists to break away from the misleading conventions imposed by statement in combinations by presenting and discussing analytical data in a form that avoids as far as possible the personal equation of the analyst. Haywood and Smith[f] have proposed for classifying on the ionic basis mineral waters in respect to their therapeutic action a scheme that will undoubtedly be entirely practicable with some additions and modifications suggested by its extended use. A system of

[a] Clarke, F. W., The data of geochemistry: Bull. U. S. Geol. Survey No. 330, 1908, p. 54.

[b] Walter, G., and Gärtner, A., Tiemann-Gärtner's Handbuch der Wasser, Braunschweig, 4th ed., 1895, p. 357. Fresenius, C. R., Quantitative chemical analysis, 2d American ed., 1897, p. 674. Stillman, T. B., Engineering chemistry, 1897, p. 65. Wanklyn, J. A., Water analysis, 9th ed., 1894, p. 110.

[c] Handy, J. O., Water softening: Eng. News, vol. 51, 1904, p. 500; also Proc. Eng. Soc. Western Pennsylvania, vol. 19, 1903, p. 659.

[d] McGill, Anthony, Boiler feed waters: Bull. Am. Ry. Eng. and Maintenance of Way Assoc. No. 6, 1905, p. 612.

[e] Kimberley, A. E., The chemical phases of a water-softening problem: Jour. Infect. Dis., Suppl. No. 1, May, 1905, p. 157.

[f] Haywood, J. K., and Smith, B. H., Mineral waters of the United States: Bull. Bur. Chem., U. S. Dept. Agr., No. 91, 1905, p. 9.

formulas evolved by Stabler[a] and based on the ionic form reduces the classification of waters for steaming and for general industrial use to mathematical certainty and makes it apparent that the fundamental data obtained by actual analysis are sufficient for determining the value of a natural water and for estimating the cost of purifying it in general industrial operations. Further evidence of the desire to effect a reform in the methods of reporting water analyses is furnished by the resolutions adopted by scientific associations. As early as 1886 a committee[b] appointed by the Chemical Society of Washington recommended that all analyses of water should be stated in terms of the radicles found, whether elementary or compound, meaning thereby the immediate results of the actual analysis; and though the committee recommended that the combinations deemed most probable by the chemist making the analysis should also be stated, they were careful to avoid any recommendation as to the manner of combining the analytical results, because the views of chemists would probably differ so much in that respect. The report of this committee was adopted by section C of the American Association for the Advancement of Science in 1887,[c] but two years later a committee of the British Association for the Advancement of Science,[d] while agreeing with the American Association in reporting the analytical data obtained by direct determination, disapproved the statement of the mineral ingredients combined as salts. Since that time many other scientific organizations in America and in Europe have recommended the statement of the actual results instead of the combinations deduced by the chemist. At the Fifth International Congress of Applied Chemistry[e] in 1903, the discussion of two papers on methods of expressing the results of a water analysis indicated that many of the chemists favored the ionic form of statement, and at the Sixth International Congress Christomanos[f] recommended that the simple statement of the acidic and basic ions in parts per million be made in all water analyses.

The ionic form of statement appeals particularly to the analytical chemist because it affords an opportunity of stating results that can be checked for their accuracy by persons other than those making the tests. When hypothetical combinations are made, one of three methods of procedure is usually followed—(1) all the bases and acids except the alkalies present in appreciable amount are estimated, and the excess of acids is computed to an equivalent of sodium and

[a] Stabler, Herman, The mineral analysis of water for industrial purposes and its interpretation by the engineer: Eng. News, vol. 60, 1908, p. 355.

[b] Bull. Chem. Soc. Washington No. 2, 1887, p. 35.

[c] Chem. News, vol. 56, 1887, p. 113.

[d] Chem. News, vol. 60, 1889, p. 203.

[e] Bericht V. Internationaler Kongress für angewandte Chemie, vol. 1, 1903, p. 261.

[f] Christomanos, A. C., Bericht über die Arbeiten der VI. Unter-Kommission der Internationalen Analysen-Kommission: Atti del VI. Congresso Internazionale di Chimica Applicata, vol. 7, 1907, p. 213.

potassium salts; or (2) all the bases and acids except the carbonates are estimated, and the excess of bases computed to an equivalent in carbonates; (3) if all the bases and acids are determined, it is necessary to "doctor" the figures of the hypothetical combinations in order properly to balance the bases and the acids. These methods of procedure effectively conceal errors of technique and leave it entirely to the judgment of the analyst whether his error of closure is too great or too little, and the evidence on which his judgment is based is completely masked because the hypothetical combinations show no error at all. On the other hand, the ionic form of statement, because it gives the determined elements and radicles, makes it possible to balance the acids against the bases and to determine the probable accuracy of the work.

In brief, it may be said that the ionic form of presenting the results of an analysis of a mineral water gives a statement of facts and not of opinion. The form is entirely practical and presents the actual results for the consideration and criticism of persons other than those making the tests. As it is in accordance with the generally accepted views based on our knowledge of chemistry, the analyses in this volume have been stated in that way.

LOCATION OF SAMPLING STATIONS.

The location of the sampling stations, the names of the collectors, and information regarding immediate surroundings likely to influence the quality of the water are given in the table which follows, and the list is arranged alphabetically by names of the rivers and lakes. If stream-gaging data are available the location of the gaging station is stated, together with its distance above (+) or below (−) the sampling station. Several factors were necessarily considered in determining the location of the points at which samples of water were to be collected. The relative importance of the streams from a geologist's standpoint, particularly in regard to denudation, was given much weight; and practical considerations in relation to the industrial uses of the waters, the procurement of collectors, the shipment of samples, and other more or less local features influenced the selection.

List of sampling stations.

Source of sample (river, except as noted) and location of sampling station.	Gaging station.		Name of collector.	Remarks regarding collection of samples.
	Location, showing distance, in miles, above (+) or below (−) sampling station	[a] Maintained by—		
Alabama, Selma, Ala	Same	G. S.; W. B	C. F. Brislin	Midstream from iron highway.
Allegheny, Kittanning, Pa	do	G. S	S. B. Cochrane	Midstream from Market Street Bridge.
Androscoggin, Brunswick, Me	None		F. C. Robinson	Above dam.
Arkansas, Little Rock, Ark	Same	W. B.; E. C	W. J. Riley	From waterworks intake.
Big Muddy, Murphysboro, Ill	do	Ill	H. C. Stagner	Do.
Big Vermilion, Danville, Ill	None		W. Van Stienberg	Do.
Brazos, Waco, Tex	Same	G. S.; W. B	W. J. Cassaday	Midstream from suspension bridge.
Cache, Mounds, Ill	do	Ill	J. F. Anderson	From intake of I. C. R. R.
Cahaba, Birmingham, Ala	Centerville, −60	G. S	D. J. O'Connell	From waterworks intake.
Cape Fear, Wilmington, N. C	Fayetteville, +75	W. B	Oscar Durant	Midstream from ferryboat.
Cedar, Cedar Rapids, Iowa	Same	G. S.; W. B	R. S. Toogood	Midstream from bridge.
Chattahoochee, West Point, Ga	do	G. S.; W. B	E. N. Dunn	Midstream from Montgomery Street Bridge.
Chippewa, Eau Claire, Wis	do	G. S	J. C. Kimpton	Midstream from highway bridge.
Colorado, Austin, Tex	Mauch Chunk	G. S.; W. B		
Cumberland:				
Nashville, Tenn	Fayetteville	W. B.; E. C	J. T. Ahearn	
Kuttawa, Ky	Clarkesville, Tenn.; +70.	W. B	W. E. Mathews	
Dan, South Boston, Va	Same	G. S	J. R. East	Midstream from railway bridge.
Delaware, Lambertville, N. J	do	G. S	C. H. Naylor	From toll bridge.
Des Moines, Keosauqua, Iowa	None		Oscar McCreary	Midstream from highway bridge.
Embarrass:				
Charleston, Ill	do		James Winkleblack, Louis Strodbeck	From waterworks intake.
Lawrenceville, Ill	do		Perry Barnhouse	From intake of C., C., C. and St. L. Ry.
Erie (Lake), Buffalo, N. Y	Same	E. C	H. L. Lyon	From waterworks intake.
Flint, Albany, Ga	do	G. S.; W. B	D. W. Brosran	Midstream from county bridge.
Fox:				
Elgin, Ill	None		R. R. Parkins	From waterworks intake.
Ottawa, Ill	do		M. P. Lannigan	From intake of C., R. I. and P. Ry.
Grand, Grand Rapids, Mich	Same	G. S	L. W. Anderson	Midstream from Fulton Street Bridge.
Hudson, Hudson, N. Y	None		E. Van Benschoten	
Huron (Lake), Port Huron, Mich	Harbor Beach, +60	E. C	J. E. Meno	Midstream, St. Clair River.
Illinois:				
La Salle, Ill	Same	G. S.; W. B	James Brotherton	From intake of I. C. R. R.
Peoria, Ill	do	G. S.; W. B	Alfred Barton	Midstream from bridge.
Kampsville, Ill	do	Ill	Ira Davidson	Midstream.
Iowa, Iowa City, Iowa	None		A. G. Smith	Do.

[a] G. S.=U. S. Geological Survey; W. B.=U. S. Weather Bureau; E. C.=Engineer Corps, U. S. Army; Ill.=Engineering Experiment Station, University of Illinois.

List of sampling stations—Continued.

Source of sample (river, except as noted) and location of sampling station.	Gaging station. Location, showing distance, in miles, above (+) or below (−) sampling station.	Gaging station. [a] Maintained by—	Name of collector.	Remarks regarding collection of samples.
James, Richmond, Va.	Same	W. B	Beverley Richardson	Above city.
Kalamazoo, Kalamazoo, Mich.	Allegan, −30	G. S	Morris Christlieb	Midstream.
Kankakee, Kankakee, Ill	None		A. L. Straley	From waterworks intake.
Kaskaskia:				
Carlyle, Ill.	Same	Ill	George Schilling	Do.
Shelbyville, Ill.	do	Ill	Isaac Nutt	Midstream from old dam.
Kentucky, Frankfort, Ky.	do	W. B	D. L. Holland	Midstream.
Lehigh, South Bethlehem, Pa.	Mauch Chunk, +30	W. B	H. M. Ueberroth	From waterworks intake.
Little Vermilion, Streator, Ill.	None		R. D. Huggans	In current.
Little Wabash, Carmi, Ill.	Newhaven, −20	Ill	Samuel Morgan	Do.
Maumee, Toledo, Ohio.	None		J. M. Wisler	From waterworks intake.
Miami, Dayton, Ohio	Same	W. B	B. F. Glass	
Michigan (Lake), St. Ignace, Mich	Mackinaw, 5	E. C	Albert Boynton	Midchannel from ferryboat.
Minnesota, Shakopee, Minn.	Mankato, +60	W. B	R. C. Strunk	Midstream from highway bridge.
Mississippi:				
Minneapolis, Minn.	Anoka, +20	G. S	J. H. McConnell	From upper waterworks intake.
Moline, Ill.	Same	Ill	Magnus Olsen	From waterworks intake.
Quincy, Ill.	Hannibal, Mo.; −15	W. B	F. J. Brinkoetter	Do.
Chester, Ill.	Same	W. B		From intake of state penitentiary.
Memphis, Tenn.	do	W. B.; E. C	T. D. Shroyer	
New Orleans, La.	Carrolton, +5	E. C	J. L. Porter	Near new filtration plant.
Missouri:				
Florence, Nebr.	Omaha, −5	W. B	J. B. Denton	
Kansas City, Kans.	Same, −7 [b]	W. B	H. A. Sickels	From Quindaro intake.
Ruegg, Mo.	Hermann, +70	W. B	William Bausch	Midstream from railroad bridge.
Monongahela, Elizabeth, Pa.	Lock No. 4, +10	W. B	F. E. Hatch	Midstream.
Muskingum, Zanesville, Ohio	Same	G. S.; W. B	C. J. Crossland	Midstream from bridge.
Neuse, Raleigh, N. C	None		A. H. Byrum	Near Milburnie.
North Platte, North Platte, Nebr.	Same	G. S	Henry Deck	Main channel from highway bridge.
Oconee, Dublin, Ga.	do	G. S.; W. B	W. E. Martin	Midstream from highway bridge.
Ocmulgee, Macon, Ga.	do	G. S.; W. B	G. E. Lawton	Midstream from bridge.
Oostanaula, Rome, Ga.	do	W. B	W. M. Chambers	At waterworks pumping station.
Oswegatchie, Ogdensburg, N. Y.	do	G. S	H. A. Lord	From waterworks intake.
Pearl, Jackson, Miss.	do	G. S.; W. B	James Hurst	Midstream from highway bridge.
Pedee, Pedee, N. C.	Cheraw, S. C., −20	W. B	Richardson	Midstream.
Platte:				
Columbus, Nebr.	Same	G. S	W. D. Benson; F. L. Hahn	Midstream from Meridian Bridge.
Fremont, Nebr.	None		C. H. Daniels	Midstream.

Potomac, Cumberland, Md	Same	W. B	Joseph L. Sell	In current.
Raritan, Bound Brook, N. J	do	G. S	J. K. Tantum	Midstream from highway bridge.
Red, Shreveport, La	do	W. B.; E. C	D. P. Irvine	Midstream from toll bridge.
Reservoir:				
Cartter, Ill	None		A. A. Justice	
Cypress, Ill	do		Garlan Adams	
Joppa, Ill	do		John Wood	
Marion, Ill	do		R. E. Coler	
Rio Grande, Laredo, Tex	Same	(c)		
Roanoke, Randolph, Va	do	G. S	J. E. Figg	Midstream from railroad bridge.
Rock:				
Rockford, Ill	Rockton, +15	G. S	F. H. Gregory	From waterworks intake.
Sterling, Ill	None		C. A. Yohn	From intake of Illinois Straw Product Co.
St. Lawrence, Ogdensburg, N. Y	Same	E. C	H. A. Lord	In midstream.
Saluda, Columbia, S. C	Chappells, +50	W. B	E. N. Chisholm, jr	In current.
Sangamon:				
Decatur, Ill	Same	Ill	Fred Litterer	From waterworks intake.
Springfield, Ill	None		Gus Obert	Do.
Chandlerville, Ill	Same	Ill	J. W. Martin, John Madden	Midstream from highway bridge.
Savannah, Augusta, Ga	do	G. S.; W. B	C. A. Maxwell	Do.
Shenandoah, Millville, W. Va	do	G. S	W. R. Nicewarner	From bank of stream.
Superior (Lake), Sault Ste. Marie, Mich	Marquette, +160	E. C	Lester Hodges, Alice Hodges	From railroad bridge above locks.
Susquehanna:				
West Pittston, Pa	Wilkes-Barre, +10	G. S.; W. B	J. A. Allan	(d)
Williamsport, Pa	Same	G. S.; W. B	H. H. Guise	Midstream from bridge.
Danville, Pa	do	G. S	E. F. Bell	Do.
Tennessee:				
Knoxville, Tenn	do	G. S.; W. B	Knoxville Water Co	In main current.
Gilbertsville, Ky	Johnsonville, Tenn.; +80.	W. B	Earle Herndon	Midstream from railroad trestle.
Tombigbee, Epes, Ala	Same	G. S	J. C. Horton	Midstream from railway bridge.
Wabash:				
Logansport, Ind	None		John Bender	Midstream above Eel River.
Vincennes, Ind	Mount Carmel, Ill.; −30.	W. B	L. J. Weisenberger	From waterworks intake.
Wateree, Camden, S. C	Same	G. S.; W. B	W. C. Brown	Midstream from bridge.
White:				
Azalia, Ind	None		L. E. Davis	
Indianapolis, Ind	do		H. E. Jordan	In main current.
Wisconsin, Portage, Wis	Necedah, −50	G. S	Charles McSorley	Midstream from steel bridge.
Youghiogheny, McKeesport, Pa	West Newton, +10	W. B	National Galvanized Works.	Midstream.

[a] G. S.= U. S. Geological Survey; W. B.= U. S. Weather Bureau; E. C.= Engineer Corps, U. S. Army; Ill.= Engineering Experiment Station, University of Illinois.
[b] The sampling station is above the entrance of Kansas River, but the gaging station is below that stream.
[c] Observations made under direction of the Mexican section of the International (Water) Boundary Commission.
[d] Samples collected by Spring Brook Water Supply Company from their intake at West Pittston till December, 1906, after which samples were collected near Forest Castle Brewery, Pittston.

ANALYTICAL RESULTS.

The following tables give the results of the analyses of certain rivers and lakes east of the one hundredth meridian. Each table presents a detailed statement of the results of the analyses of composite samples, arranged in chronological order, followed by lines showing the mean of the analyses and the chemical composition of the anhydrous residue. Wherever gage heights were available they were averaged in sets corresponding to the sampling periods, and this computed average is included in the table.

At the end of the detailed analyses is a table in which the lines showing average quality of the waters analyzed both in parts per million of mineral matter and in percentage composition of the anhydrous residues are assembled. The list of localities in this last table includes 27 in the State of Illinois not included in the preceding detailed statements.

Mineral analyses of water from Alabama River at Selma, Ala.[a]

[Parts per million, unless otherwise stated.]

Date (1906–7).		Turbidity.	Suspended matter.	Coefficient of fineness.	Total iron (Fe).	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.	Mean gage height (feet).
From—	To—																
Nov. 5	Nov. 17	65	22	0.34	.....	19	0.7	12	1.6	.....	0.0	46	.....	0.3	0.2	79	3.8
Nov. 18	Nov. 27	180	97	.54	.....	40	.6	12	.8	.....	.0	41	.....	.5	2.0	91	17.1
Nov. 28	Dec. 7	155	118	.76	.....	34	.8	11	1.2	.....	.0	39	.....	.6	1.8	82	11.0
Dec. 8	Dec. 17	180	145	.80	.....	31	.5	9.6	1.6	.....	.0	32	.....	.3	2.0	78	7.0
Dec. 18	Jan. 1	80	49	.61	.....	20	.5	11	Tr.	.....	.0	31	.....	.4	.....	78	10.7
Jan. 2	Jan. 13	50	42	.84	.....	21	.20	8.3	4.4	.....	.0	44	.....	.3	3.5	83	19.5
Jan. 14	Jan. 23	35	21	.60	.....	20	.40	16	2.8	.....	.0	44	.....	.8	3.2	73	7.7
Jan. 24	Feb. 2	65	45	.69	.....	26	.30	8.4	1.6	.....	.0	37	.....	.1	4.5	67	7.5
Feb. 3	Feb. 12	100	62	.62	.....	26	.5	8.2	2.4	.....	.0	32	.....	.8	2.8	66	27.9
Feb. 13	Feb. 24	25	19	.76	.....	10	.5	14	1.2	.....	.0	44	.....	.4	3.0	58	9.4
Feb. 25	Mar. 6	260	195	.75	.....	22	.10	15	2.0	.....	.0	46	.....	.3	1.0	79	23.0
Mar. 7	Mar. 16	160	124	.78	.....	28	.10	10	1.2	.....	.0	34	.....	.5	3.0	70	20.8
Mar. 17	Mar. 26	95	86	.91	.....	20	.20	15	1.2	.....	.0	49	.....	.3	1.5	70	9.3
Mar. 27	Apr. 5	40	41	1.02	.....	20	.20	16	1.6	.....	.0	51	.....	.4	2.5	72	6.3
Apr. 6	Apr. 15	95	89	.93	.....	22	.40	15	5.2	.....	.0	58	.....	.1	1.5	80	7.4
Apr. 16	Apr. 25	195	176	.90	.....	22	.5	12	5.2	.....	.0	51	.....	.2	3.0	76	13.3
Apr. 26	May 5	220	184	.84	.....	30	.40	10	3.6	.....	.0	41	.....	.1	2.0	74	16.1
May 6	May 15	90	70	.78	.....	19	.40	12	2.8	.....	.0	.....	.....	.1	2.5	63	16.5
May 16	May 25	312	228	.73	.....	13	1.2	13	2.3	3.2	.0	43	10	1.3	1.2	94	23.9
May 26	June 3	165	117	.71	.....	15	1.0	11	2.6	.....	.0	48	13	.4	1.8	90	12.7
June 6	June 15	195	157	.80	.....	25	1.3	13	2.8	5.6	.0	46	9.4	1.6	1.7	98	9.9
June 16	June 25	90	101	1.12	.....	17	.5	15	4.8	6.7	.0	....	14	1.2	2.4	90	6.0
June 26	July 6	205	139	.68	.....	11	.35	18	2.3	6.7	.0	61	8.7	.9	2.1	86	7.2
July 7	July 16	210	126	.60	.....	22	1.1	15	4.5	5.5	.0	55	.....	1.6	2.1	104	4.0
July 17	July 26	125	86	.69	.....	16	.48	17	5.8	.....	.0	67	10	1.6	3.0	105	4.4
July 28	Aug. 6	325	203	.62	.....	17	1.1	15	5.3	8.9	[b]Tr.	50	13	1.2	1.8	99	5.4
Aug. 7	Aug. 17	230	141	.61	.....	25	1.0	15	.....	9.5	.0	....	12	1.6	2.7	101	3.8
Aug. 18	Aug. 27	160	58	.36	.....	23	1.2	13	.....	7.8	.0	60	9.4	1.1	2.0	110	2.7
Aug. 28	Sept. 6	100	59	.59	.....	21	1.0	16	4.8	5.7	.0	59	8.7	.4	2.5	105	1.4
Sept. 8	Sept. 17	80	65	.81	2.2	21	Tr.	15	4.0	8.1	.0	68	4.8	1.0	2.2	88	2.1
Sept. 18	Sept. 27	90	70	.78	2.2	17	.03	14	4.1	7.4	.0	66	5.0	1.0	2.4	82	2.0
Sept. 28	Oct. 7	180	105	.58	2.8	11	Tr.	12	3.0	6.7	.0	56	3.7	1.1	2.4	64	4.7
Oct. 8	Oct. 17	90	50	.56	1.	12	.03	12	2.9	9.0	.0	57	4.4	.9	2.3	68	1.5
Mean		141	100	.72	.....	21	.53	13	2.9	7.0	.0	48	9.0	.7	2.3	82	.....
Per ct. of anhydrous residue		.....	.....	.....	.....	26.2	c.9	16.2	3.6	8.7	29.4	....	11.2	.9	2.9	.....	.....

[a] Analyses November 5, 1906, to May 15, 1907, by J. R. Evans; May 16 to September 6, 1907, by Walton Van Winkle; September 8 to October 17, 1907, by R. B. Dole, Chase Palmer, and W. D. Collins.
[b] Abnormal; computed as HCO_3 in the average.
[c] Fe_2O_3.

Mineral analyses of water from Allegheny River at Kittanning, Pa.[a]

[Parts per million, unless otherwise stated.]

Date (1906–7).		Turbidity.	Suspended matter.	Coefficient of fineness.	Total iron (Fe).	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.	Mean gage height (feet).
From—	To—																
Sept. 13	Sept. 23	19	26	1.37	0.2	12	Tr.	21	4.2	19	0.0	51	35	0.0	28	140	2.49
Sept. 24	Oct. 3	15	21	1.40	1.2	8.6	0.06	22	4.0	19	.0	61	25	Tr.	29	142	2.86
Oct. 4	Oct. 14	46	69	1.50	3.5	6.0	Tr.	18	2.0	12	.0	40	19	.6	20	107	5.68
Oct. 15	Oct. 24	21	28	1.33	1.2	11	Tr.	14	1.8	11	.0	34	13	.4	13	87	5.51
Oct. 25	Nov 3	29	63	1.24	1.5	9.2	.1	12	2.2	9.6	.0	37	12	.6	12	81	5.94
Nov. 4	Nov. 14	5	5.2	1.04	.2	7.8	.1	12	1.8	7.6	.0	36	14	.7	13	77	5.11
Nov. 15	Nov. 25	29	45	1.55	2.0	4.4	.2	12	2.2	9.3	.0	37	14	.9	12	74	7.67
Nov. 27	Dec. 5	8	5.2	.65	.2	6.0	.1	12	2.0	9.1	.0	33	14	.9	11	71	5.49
Dec. 6	Dec. 16	65	86	1.32	2.6	4.8	.15	10	3.0	4.4	.0	26	12	1.5	8.2	59	10.30
Dec. 17	Dec. 26	13	13	1.00	.9	7.6	.17	10	3.2	5.0	.0	26	13	1.1	8.4	63	7.79
Dec. 27	Jan. 5	36	40	1.11	1.6	6.2	.22	11	3.6	7.1	.0	28	16	1.7	11	73	8.15
Jan. 7	Jan. 15	38	41	1.08	1.4	5.4	.21	8.5	2.0	5.7	.0	21	12	1.0	6.7	54	11.20
Jan. 16	Jan. 25	35	48	1.37	1.8	5.4	.21	9.2	2.2	5.2	.0	19	14	1.1	7.4	55	10.20
Jan. 26	Feb. 5	6	4.2	.70	.5	7.4	.2	13	3.8	9.1	.0	32	23	1.1	10	80	5.63
Feb. 6	Feb. 16	4	2.6	.65	.4	6.8	.16	15	3.4	9.0	.0	41	23	1.2	13	89	4.60
Feb. 18	Feb. 27	6	6.0	1.00	.2	2.4	.09	16	3.4	9.8	[b]9.4	22	22	.6	16	85	4.89
Feb. 28	Mar. 10	5	2.0	.40	.4	6.8	.13	14	3.2	9.3	.0	34	20	1.1	13	83	5.27
Mar. 11	Mar. 20	....	179	.....	6.5	7.0	.3	9.2	2.2	8.0	.0	28	16	1.5	8.2	65	11.46
Mar. 21	Mar. 31	27	53	1.96	1.5	3.8	.10	7.4	1.6	5.4	.0	24	12	.6	6.0	47	11.47
Apr. 1	Apr. 10	8	7.6	.95	.7	7.0	.13	10	2.6	7.2	.0	29	14	1.3	9.4	67	7.11
Apr. 11	Apr. 20	5	5.4	1.08	.4	6.4	.10	12	2.8	9.4	.0	27	16	1.0	12	73	5.77
Apr. 21	Apr. 30	40	30	.75	1.1	12	.16	9.6	2.4	9.1	.0	27	14	1.0	10	72	8.16
May 1	May 11	19	22	1.16	.9	11	.10	8.6	2.2	9.1	.0	29	12	1.0	7.6	66	8.06
May 11	May 20	19	17	.89	.6	17	.18	10	2.0	8.8	.0	37	12	.7	11	81	6.48
May 21	May 30	29	30	1.04	1.0	5.4	.10	10	1.6	8.0	.0	30	12	.6	11	64	6.99
May 31	June 9	36	29	.80	1.3	14	.15	10	1.9	8.8	.0	43	10	.5	9.1	78	7.82
June 10	June 20	20	22	1.10	.8	7.2	.10	10	2.0	8.5	.0	35	14	.3	9.7	71	6.28
June 26	June 30	18	24	1.33	1.0	7.6	.11	14	2.0	13	.0	45	14	.4	13	88	4.92
July 1	July 10	28	36	1.28	1.2	12	.15	14	2.8	11	.0	44	14	.7	13	89	5.25
July 12	July 22	15	23	1.53	1.0	10	.14	15	3.4	12	.0	45	18	.6	14	94	4.21
July 23	Aug. 1	26	30	1.15	1.1	9.0	.14	17	4.0	14	.0	50	22	.3	17	109	3.27
Aug. 2	Aug. 11	15	19	1.27	.6	10	.12	18	4.4	15	.0	51	22	.3	17	111	2.98
Aug. 12	Aug. 21	5	7.6	1.52	.3	5.4	.10	23	5.4	19	.0	63	26	.2	25	132	1.92
Aug. 22	Aug. 31	2	2.4	1.20	.2	6.4	.13	26	6.0	21	.0	71	30	.1	32	154	1.75
Sept. 1	Sept. 10	19	24	1.26	1.1	8.0	.19	25	6.0	22	.0	67	32	.2	32	155	1.99
Mean		21	30	1.14	1.2	7.9	.13	14	3.0	11	.0	38	17	.7	14	87	.....
Per ct. of anhydrous residue		.....	.....	.....	.....	9.1	c.2	16.1	3.5	12.7	21.9	....	19.6	.8	16.1	....	.....

[a] Analyses September 13 to December 5, 1906, by R. B. Dole; December 6, 1906, to March 31, 1907, by R. B. Dole and M. G. Roberts; March 4 to September 10, 1907, by Chase Palmer and M. G. Roberts.

[b] Abnormal; computed as HCO_3 in the average.

[c] Fe_2O_3.

Mineral analyses of water from Androscoggin River at Brunswick, Me.[a]

[Parts per million, unless otherwise stated.]

Date (1905–6).	Silica (SiO_2).	Fe_2O_3+ Al_2O_3.	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Total dissolved solids.
Apr. 25	6.6	2.1	3.6	1.4	1.7	0.7	.....	6.4	3.0	27
May 2	6.0	1.8	4.6	.8	2.0	.9	.....	9.2	3.3	30
May 9	5.5	1.0	3.7	.6	2.0	.7	.....	9.5	1.0	25
May 16	5.4	1.4	4.3	1.3	1.9	.6	.....	8.2	.6	26
May 23	5.3	1.4	4.4	1.3	1.9	.8	.....	8.6	.9	26
May 30	5.8	2.9	5.8	.9	2.2	1.0	.....	9.6	.9	31
June 6	7.3	3.1	6.2	1.0	2.4	1.3	.....	11	.8	35
June 13	7.5	2.0	6.3	1.5	2.4	.9	.....	11	1.2	35
June 20	6.5	1.8	6.0	1.5	2.0	.8	.....	11	.6	32
June 27	7.8	3.3	6.9	1.2	2.4	.9	.....	9.7	.4	35
July 4	7.5	2.6	5.6	1.2	2.5	.9	.....	9.4	.9	33
July 11	9.5	1.7	5.8	1.7	2.1	.8	.....	11	2.6	37
July 18	8.1	3.2	7.2	1.7	2.5	.8	.....	14	.9	41
July 25	10	4.1	6.1	1.5	2.7	1.2	.....	12	3.0	43
Aug. 1	9.8	3.3	6.3	2.0	2.4	.9	.....	13	3.9	44
Aug. 8	6.7	2.2	5.5	1.4	2.8	.7	.....	9.6	3.5	34
Aug. 15	7.0	2.2	6.9	2.1	2.6	.8	.....	14	3.7	41
Aug. 22	7.6	2.1	6.9	2.0	2.1	1.1	.....	13	3.9	40
Aug. 29	6.8	4.0	7.9	1.6	2.8	1.0	.....	12	3.9	43
Sept. 5	9.0	3.0	8.4	2.2	2.8	1.4	.....	16	3.5	49
Sept. 12	7.4	1.8	5.9	1.1	2.2	.9	.....	8.8	3.5	33
Sept. 19	9.9	4.9	7.7	1.7	3.4	.6	.....	13	3.9	48
Sept. 26	6.2	2.7	8.8	.6	1.3	.7	.....	14	3.0	40
Oct. 3	9.6	2.7	8.4	.7	3.2	.8	.....	14	3.0	48
Oct. 10	9.3	3.1	14	.9	3.8	.9	.....	8.9	1.2	51
Oct. 17	13	4.1	13	.6	3.4	.9	.....	14	3.9	56
Oct. 24	8.3	4.9	11	1.5	3.0	.9	.....	13	3.5	49
Oct. 31	9.4	3.9	7.5	.7	1.7	.7	.....	13	3.0	39
Nov. 7	13	4.6	9.3	.6	1.9	1.6	.....	14	3.5	52
Nov. 15	14	4.6	7.0	.7	3.2	1.2	.....	8.8	3.3	47
Nov. 21	14	3.6	7.8	.8	3.7	1.2	.....	16	3.5	52
Nov. 28	14	4.7	7.7	.7	3.4	1.1	.....	12	3.5	52
Dec. 5	12	5.9	7.9	.3	3.0	1.2	.....	9.1	1.2	45
Dec. 12	7.5	4.1	8.4	.5	2.6	.9	.....	11	1.0	40
Dec. 19	10	3.2	11	.7	2.4	.8	.....	6.4	1.2	49
Dec. 26	9.5	4.5	10	.6	3.3	1.5	.....	16	3.5	53
Jan. 2	9.9	2.0	6.0	1.6	2.3	1.3	.....	15	1.2	47
Jan. 9	11	5.5	9.3	.5	2.4	1.5	.....	9.7	.9	47
Jan. 16	11	2.9	11	1.0	1.7	1.4	.....	15	1.0	52
Jan. 23	10	4.2	8.5	.6	2.8	1.3	.....	10	1.2	43
Jan. 30	8.0	1.8	6.0	.5	3.0	1.3	.....	8.8	.5	34
Feb. 6	9.5	4.6	6.8	.5	2.7	1.4	.....	11	.9	42
Feb. 13	11	2.5	7.2	1.7	2.6	1.3	.....	17	1.2	50
Feb. 20	11	4.0	12	.8	2.2	1.2	.....	15	.4	52
Feb. 27	14	4.3	7.9	.9	2.2	1.2	.....	14	.8	49
Mar. 6	.....	2.6	5.6	.8	2.5	1.2	.....	9.4	3.0	53
Mar. 13	12	2.8	8.8	1.2	2.5	1.4	.....	16	3.5	52
Mar. 20	14	4.9	10	1.2	3.6	1.5	.....	16	3.5	56
Mar. 27	11	4.9	11	.9	2.3	1.3	.....	13	3.3	52
Apr. 3	6.0	3.4	5.6	.6	1.9	1.0	.....	6.1	2.8	31
Apr. 10	4.9	2.0	3.6	.8	2.0	.7	.....	8.9	3.6	27
Apr. 17	4.0	1.0	3.4	.6	1.7	.8	.....	8.7	3.0	24
Mean	9.0	3.2	7.4	1.1	2.5	1.0	.....	12	2.3	42
Per ct. of anhydrous residue[b]	18.6	6.6	15.3	2.3	5.2	2.1	20.3	24.8	4.8	.....

[a] Analyses by F. C. Robinson.
[b] Based on the assumption that the average content of bicarbonates is 20 parts.

Mineral analyses of water from Arkansas River near Little Rock, Ark.[a]

[Parts per million, unless otherwise stated.]

Date (1906–7). From—	To—	Turbidity.	Suspended matter.	Coefficient of fineness.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.	Mean gage height (feet).
Nov. 1	Nov. 10	270	172	0.64	31	0.30	84	18	351	0.0	230	136	1.8	535	1,285	3.5
Nov. 11	Nov. 20	140	96	.69	20	.30	86	22	381	.0	221	149	Tr.	568	1,339	3.6
Nov. 21	Dec. 2	140	135	.96	24	.9	39	11	123	.0	115	72	.5	186	519	5.2
Dec. 3	Dec. 19	1,000	894	.89	47	2.4	53	14	180	.0	142	95	.4	276	752	8.0
Dec. 20	Jan. 11	320	294	.92	31	1.2	25	8.9	60	.0	76	57	1.5	80	304	10.4
Dec. 14	Jan. 31	1,320	1,567	1.19	...	...	40	13	62	.0	106	...	2.4	87	451	15.2
Feb. 2	Feb. 20	275	206	.75	20	.40	57	12	83	.0	155	63	3.8	107	433	8.6
Feb. 21	Mar. 7	220	228	1.04	16	.25	54	13	...	.0	144	74	3.4	...	460	8.1
Mar. 8	Mar. 28	450	413	.92	25	1.8	42	9.5	67	.0	131	61	1.2	82	366	9.5
Mar. 29	Apr. 12	235	233	.99	19	.8	45	11	80	.0	140	67	1.5	103	412	6.8
Apr. 13	Apr. 22	290	227	.78	20	.9	32	8.7	49	.0	106	42	1.2	65	287	7.3
Apr. 23	May 2	285	192	.67	22	1.2	42	11	74	.0	102	56	2.0	102	377	7.0
May 3	May 13	1,500	1,073	.72	54	1.8	27	6.9	33	.0	86	32	3.6	37	279	18.0
May 14	May 23	860	961	1.12	56	2.2	32	5.6	41	.0	92	43	6.3	40	305	17.4
May 24	June 2	450	460	1.02	40	1.0	31	2.7	31	.0	100	34	1.8	34	271	11.4
June 20	July 18	2,800	2,730	.97	20	.30	49	13	80	.0	181	72	2.8	87	414	10.6
July 19	Aug. 5	270	165	.61	18	.10	66	17	157	.0	196	103	1.1	213	695	5.3
Aug. 8	Aug. 17	1,000	834	.83	29	.15	96	20	415	.0	181	211	1.5	610	1,500	5.3
Aug. 18	Aug. 29	600	480	.80	13	.06	95	23	261	.0	195	212	4.4	347	1,093	4.0
Aug. 30	Sept. 8	3,000	4,119	1.37	36	.12	71	20	155	.0	189	153	1.3	181	736	5.0
Sept. 9	Oct. 6	280	162	.58	26	.33	72	17	179	[b]8.4	184	117	.3	265	806	2.8
Oct. 7	Oct. 24	900	811	.90	26	.8	72	16	155	[b]Tr.	157	98	.2	262	774	3.3
Mean		755	748	.88	28	.82	55	13	144	.0	148	93	2.0	203	630	.....
Per ct. of anhydrous residue		.....	.....	....	4.6	[c].2	9.0	2.1	23.5	11.9	.....	15.2	.3	33.2	.....	....

[a] Analyses November 1, 1906, to January 31, 1907, by W. M. Barr; February 2 to 20, 1907, by Henry S. Spaulding; February 21 to September 8, 1907, by Walton Van Winkle; September 9 to October 24, 1907, by R. B. Dole, Chase Palmer, and W. D. Collins.

[b] Abnormal; computed as HCO_3 in the average.

[c] Fe_2O_3.

Mineral analyses of water from Brazos River near Waco, Tex.[a]

[Parts per million, unless otherwise stated.]

Date (1906–7).		Turbidity.	Suspended matter.	Coefficient of fineness.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.	Mean gage height (feet).
From—	To—															
Dec. 14	Dec. 25	675	669	0.99	23	Tr.	113	14	247	0.0	159	222	1.7	382	1,113	4.9
Dec. 26	Jan. 5	110	39	.35	15	0.5	126	20	313	.0	198	241	1.8	533	1,430	3.9
Jan. 6	Jan. 15	30	28	.93	12	.5	102	18	190	.0	197	181	3.5	315	952	3.8
Jan. 16	Jan. 25	30	43	1.44	12	Tr.	107	20	258	.0	182	231	1.7	392	1,128	3.6
Jan. 27	Feb. 6	10	9.6	.96	14	Tr.	129	27	373	.0	195	266	.8	575	1,513	3.6
Feb. 7	Feb. 16	10	18	1.80	16	Tr.	103	24	265	.0	204	197	1.1	354	1,114	3.5
Feb. 17	Feb. 26	20	25	1.25	11	.05	131	30	376	.0	190	276	4.4	564	1,532	3.4
Feb. 27	Mar. 10	20	18	.90	12	.03	77	19	257	.0	242	222	1.7	293	1,004	3.3
Mar. 11	Mar. 20	45	31	.69	12	.05	86	21	193	.0	190	175	.7	283	890	3.0
Mar. 21	Mar. 30	40	48	1.20	14	.05	93	20	267	.0	196	242	Tr.	322	1,068	3.7
Mar. 31	Apr. 9	30	13	.43	11	.10	81	19	182	.0	166	188	Tr.	253	808	3.3
Apr. 11	Apr. 21	75	48	.64	15	.20	88	22	184	.0	171	216	4.2	253	892	2.8
Apr. 22	May 1	20	21	1.05	12	.02	70	22	163	.0	163	202	1.1	228	826	2.6
May 2	May 11	3,100	1,935	.62	65	.9	71	19	94	.0	149	139	3.2	124	648	4.7
May 13	May 22	6,100	4,432	.73	60	1.1	70	7.8	82	.0	140	90	4.2	121	547	6.0
May 23	June 1	4,000	3,400	.85	11	.02	60	6.3	69	.0	118	84	5.6	119	420	7.0
June 2	June 11	6,800	4,936	.72	19	.15	104	13	.....	.0	127	193	4.1	.	908	6.6
June 12	June 21	2,100	1,826	.87	9.6	.02	131	16	182	.0	110	320	5.1	297	1,077	4.8
June 22	July 1	6,400	5,350	.83	31	.5	218	26	346	.0	119	555	1.5	533	1,848	6.4
July 2	July 11	2,000	1,231	.62	26	.6	105	13	155	.0	136	260	2.2	201	848	4.4
July 12	July 22	5,400	4,482	.83	20	.07	136	23	201	.0	123	390	6.0	270	1,161	7.9
July 24	Aug. 2	1,650	1,090	.66	16	.16	99	16	108	.0	127	212	2.6	133	696	4.4
Aug. 3	Aug. 12	262	250	.95	27	.01	149	21	215	.0	133	324	.5	295	1,186	4.0
Aug. 13	Aug. 22	300	194	.65	26	.09	194	26	344	.0	134	494	.4	470	1,677	3.9
Aug. 23	Sept. 1	10	22	2.20	23	.09	178	27	308	.0	147	450	.4	451	1,618	3.5
Sept. 2	Sept. 10	5	.....	.....	18	.10	182	28	326	.0	164	451	Tr.	468	1,638	3.0
Sept. 11	Sept. 20	8	29	3.62	59	.7	150	20	300	[b] 6.2	129	377	.	418	1,442	2.9
Sept. 21	Sept. 30	18	23	1.28	31	.26	162	15	306	[b] 3.6	140	402	..	427	1,458	3.0
Oct. 1	Oct. 10	2,200	2,270	1.03	21	.8	118	13	181	[b] 3.6	146	247	..	253	937	5.6
Nov. 11	Nov. 19	2,400	1,980	.83	29	.9	206	7.8	314	[b] 6.0	98	523	.....	482	1,695	5.0
Mean		1,462	1,188	1.03	22	.26	121	19	234	.0	158	279	2.2	338	1,136	.....
Per ct. of anhydrous residue		.....	.....	.....	2.0	c 0	11.1	1.7	21.4	7.1	.....	25.5	.2	31.0	.....	.....

[a] Analyses December 14, 1906, to February 6, 1907, by W. M. Barr; February 7 to February 26, 1907, by H. S. Spaulding; February 27 to September 10, 1907, by Walton Van Winkle; September 11 to November 19, 1907, by R. B. Dole, Chase Palmer, and W. D. Collins.

[b] Abnormal; computed as HCO_3 in the average.

[c] Fe_2O_3.

Mineral analyses of water from Cahaba River near Birmingham, Ala.[a]

[Parts per million, unless otherwise stated.]

Date (1906–7). From—	To—	Turbidity.	Suspended matter.	Coefficient of fineness.	Total iron (Fe).	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.	Mean gage height (feet).[b]
Nov. 1	Nov. 11	50	16	0.32	....	20	0.20	14	1.6	....	0.0	46	....	0.9	3.0	78	2.2
Nov. 12	Nov. 21	20	7.2	.36	....	20	.30	14	2.4	.....	.0	46	.....	.8	1.5	72	4.5
Nov. 22	Dec. 1	55	36	.65	....	21	.40	12	3.6	.....	.0	49	.....	.9	1.8	70	4.2
Dec. 3	Dec. 13	75	41	.55	....	23	.5	12	....	.....	.0	51	....	.7	1.5	74	3.6
Dec. 24	Jan. 2	100	74	.74	....	20	.40	8.8	0.8	.....	.0	29	.....	.8	2.5	73	8.8
Jan. 8	Jan. 19	15	9.6	.64	....	14	.20	9.9	1.2	.....	.0	34	.....	.9	3.4	66	4.8
Jan. 20	Jan. 31	15	12	.80	....	16	.6	13	....	.....	.0	49	.....	.4	2.7	72	5.2
Feb. 1	Feb. 11	35	15	.43	....	23	.40	6.4	1.2	.....	.0	24	.....	.6	1.8	44	14.3
Feb. 12	Feb. 23	5	3.6	.72	....	8.6	.20	13	Tr.	.....	.0	41	.....	.2	1.5	53	4.2
Feb. 24	Mar. 5	18	15	.83	....	12	.20	11	1.2	.....	.0	34	.....	.5	1.5	49	11.6
Mar. 6	Mar. 15	25	20	.80	....	13	.30	12	1.6	.....	.0	41	.....	.3	2.5	59	5.6
Mar. 16	Mar. 25	10	7.0	.70	....	10	.30	14	1.2	.....	.0	46	.....	.4	2.0	59	3.7
Mar. 26	Apr. 4	10	7.6	.76	....	16	.30	15	2.8	.....	.0	54	.....	.3	1.5	75	2.9
Apr. 5	Apr. 14	25	23	.92	....	23	.30	18	1.6	.....	.0	58	.....	.3	3.0	92	4.0
Apr. 15	Apr. 24	90	82	.91	....	14	1.4	10	0.8	.....	.0	37	.....	.2	2.5	52	11.1
Apr. 25	May 2	265	260	.98	....	19	1.9	9.0	1.2	.....	.0	32	.....	.1	1.0	50	8.4
May 5	May 14	100	75	.75	....	14	1.2	7.1	3.0	8.8	.0	44	3.6	.7	2.0	62	9.0
May 15	May 24	35	29	.83	....	15	.40	8.5	3.6	6.0	.0	41	4.9	.6	2.5	68	12.2
May 25	June 3	130	119	.92	....	13	.8	8.9	2.9	7.4	.0	42	5.6	.3	2.5	66	8.0
June 4	June 13	10	10	1.00	....	22	.40	8.3	3.6	5.7	.0	53	4.6	.3	3.0	78	4.1
June 14	June 24	20	15	.75	....	18	.6	11	4.0	6.3	.0	60	6.9	.6	3.0	87	3.3
June 25	July 8	20	2.0	.10	....	21	.5	15	3.6	6.0	.0	76	9.5	.8	2.0	99	2.7
July 9	July 19	15	4.0	.27	....	19	.30	16	3.8	11	.0	74	10	.2	3.0	96	2.4
July 20	July 31	8	9.0	1.12	Tr.	19	Tr.	22	4.7	10	.0	84	11	1.0	2.4	107	2.7
Aug. 1	Aug. 11	7	8.4	1.20	Tr.	11	Tr.	....	4.1	8.7	.0	55	9.5	1.2	3.0	88	2.1
Aug. 12	Aug. 21	5	9.0	1.80	Tr.	12	Tr.	20	4.0	12	.0	78	10	.8	2.2	99	2.2
Aug. 22	Sept. 5	5	5.6	1.12	Tr.	15	Tr.	23	2.9	12	[c] 4.8	80	9.9	1.2	3.8	108	1.6
Sept. 29	Oct. 9	35	27	.77	1.0	.....	.8	14	2.7	11	[c] Tr.	70	12	.8	.6	127	2.1
Oct. 10	Oct. 22	8	12	1.50	.5	13	.22	16	3.0	10	[c] Tr.	60	12	.5	1.4	80	1.6
Oct. 23	Nov. 1	6	7.4	1.20	Tr.	10	Tr.	....	3.0	12	.0	57	13	.3	2.4	86	1.4
Mean		40	32	.81	....	16	.44	13	2.5	9.1	.0	52	8.8	.6	2.2	76	.....
Per ct. of anhydrous residue		....	.....	.....	....	20.4	[d] .8	16.6	3.2	11.6	32.7	.....	11.2	.7	2.8	....	.....

[a] Analyses November 1, 1906, to May 2, 1907, by J. R. Evans; May 14 to July 19, 1907, by W. D. Collins; July 31 to December 1, 1907, by R. B. Dole, Chase Palmer, and W. D. Collins.
[b] Gaging station near Centerville, Ala., 75 miles above.
[c] Abnormal; computed as HCO_3 in the average.
[d] Fe_2O_3.

Mineral analyses of water from Cape Fear River at Wilmington, N. C.[a]

[Parts per million, unless otherwise stated.]

Date (1906–7). From—	To—	Turbidity.	Suspended matter.	Coefficient of fineness.	Total iron (Fe).	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.	Mean gage height (feet).[b]
Oct. 2	Oct. 8	11	10	0.91	1.2	10	0.6	5.4	1.0	6.3	0.0	22	2.6	0.0	6.0	64	5.4
Oct. 10	Oct. 23	c 16	c 17	c 1.06	c .9	c 10	c .7	c 7.2	c 7.6	c 67	c .0	c 20	c 12	c .0	c 130	c 247	c 4.9
Oct. 25	Nov. 5	11	7.8	.71	.5	8.8	.5	4.8	1.0	6.6	.0	20	2.6	.0	6.2	65	4.8
Nov. 6	Nov. 17	12	10	.83	.6	10	.6	4.6	1.0	6.9	.0	22	2.3	.0	6.5	63	3.6
Nov. 18	Nov. 27	9	8.2	.91	.5	10	.5	4.4	.8	5.7	.0	22	2.3	.0	6.0	59	4.0
Nov. 28	Dec. 7	11	11	1.00	.4	11	.4	5.0	1.0	5.8	.0	22	2.8	.0	6.2	52	2.9
Dec. 8	Dec. 17	14	13	.93	.4	12	.5	5.6	1.2	7.6	.0	29	3.3	.2	6.1	61	4.7
Dec. 18	Dec. 30	19	19	1.00	.9	10	.4	4.6	1.6	6.5	.0	20	2.5	Tr.	.....	53	7.6
Dec. 31	Jan. 9	11	11	1.00	.8	10	.54	5.0	1.0	6.9	.0	....	3.1	.0	6.5	56	5.8
Jan. 10	Jan. 20	17	17	1.00	.9	8.2	.37	5.0	.6	5.3	.0	22	2.3	Tr.	5.8	44	4.3
Jan. 21	Feb. 1	11	10	.91	.6	10	.4	4.8	1.0	6.8	.0	22	2.8	.0	4.6	52	4.1
Feb. 2	Feb. 13	19	24	1.26	1.0	9.8	.53	4.8	1.0	5.6	.0	27	2.3	1.8	6.1	55	8.9
Feb. 14	Feb. 27	21	32	1.52	1.4	8.6	.61	3.8	.6	4.8	.0	18	2.5	Tr.	6.0	45	10.6
Feb. 28	Mar. 14	29	32	1.10	1.5	7.6	.81	3.8	.6	4.9	.0	21	2.8	.3	5.0	47	13.7
Mar. 15	Mar. 26	29	42	1.45	2.3	18	1.8	4.0	.8	6.4	.0	23	2.6	.0	4.6	65	11.3
Mar. 27	Apr. 6	27	25	.93	1.6	11	1.0	4.4	.8	.....	.0	22	2.8	.4	5.8	50	6.4
Apr. 8	Apr. 18	42	28	.67	2.3	.....	2.1	4.2	.6	.....	.....	.....	2.5	1.0	.....	.....	10.1
Apr. 19	Apr. 30	32	24	.75	1.9	15	1.7	4.4	1.0	6.9	.0	22	2.6	.75	4.6	62	12.5
May 1	May 11	31	25	.81	1.6	14	1.1	4.4	1.4	6.8	.0	24	1.6	.5	6.1	60	10.9
May 13	May 24	28	20	.71	1.2	8.0	.35	4.2	1.0	7.7	.0	20	2.0	.5	6.0	52	6.0
May 25	June 6	25	15	.60	1.0	7.0	.28	4.6	.8	7.9	.0	22	1.6	.5	6.6	50	10.4
June 8	June 21	28	25	.89	1.4	9.2	.75	4.2	1.0	9.0	.0	24	1.6	.5	6.2	58	10.9
June 24	July 4	32	26	.81	1.8	7.2	.65	4.8	1.2	6.1	.0	26	2.0	.3	7.0	62	9.6
July 6	July 17	....	43	.....	1.2	2.6	.13	6.6	.6	11	.0	34	4.0	.0	4.8	48	5.4
July 19	Aug. 1	....	24	.....	1.4	7.6	.88	5.4	1.8	6.6	.0	26	5.4	Tr.	5.4	57	4.4
Aug. 2	Aug. 12	....	18	.....	1.5	6.2	.61	6.4	.6	9.1	.0	29	6.9	Tr.	4.8	56	4.0
Aug. 13	Aug. 24	20	16	.80	1.4	11	1.1	5.5	2.0	12	.0	41	5.8	Tr.	5.4	66	6.6
Aug. 26	Sept. 5	20	19	.95	1.4	8.8	.77	6.5	.8	5.7	.0	24	5.1	Tr.	5.0	61	5.8
Sept. 6	Sept. 18	75	52	.69	4.0	14	1.8	5.6	1.8	8.5	.0	28	5.3	.5	6.6	68	6.4
Sept. 30	Oct. 9	15	14	.93	1.4	11	.79	8.3	1.8	12	.0	39	5.6	Tr.	7.0	75	3.7
Mean		73	21	.92	1.3	9.9	.78	5.0	1.5	7.2	.0	25	3.2	.2	5.8	57	.....
Per ct. of anhydrous residue		....	.....	.....	.....	21.6	d 2.4	10.9	3.3	15.7	26.1	....	7.0	.4	12.6	.....	.....

[a] Analyses October 2 to November 27, 1906, by R. B. Dole; November 28, 1906, to April 6, 1907, by R. B. Dole and M. G. Roberts; April 8 to July 4, 1907, by Chase Palmer and M. G. Roberts; July 6 to October 9, 1907, by R. B. Dole, Chase Palmer, and W. D. Collins.

[b] Gaging station near Fayetteville, N. C., 75 miles above.

[c] Abnormal; omitted from the average.

[d] Fe_2O_3.

Mineral analyses of water from Cedar River near Cedar Rapids, Iowa.[a]

[Parts per million, unless otherwise stated.]

Date (1906–7).		Turbidity.	Suspended matter.	Coefficient of fineness.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.	Mean gage height (feet).
From—	To—															
Sept. 6	Sept. 15	80	51	0.64	20	.	29	18	14	[b] 4.8	153	24	0.0	4.3	171	3.5
Sept. 16	Sept. 25	60	59	.98	25	0.10	32		8.7	.0	149	27	2.4	3.0	203	4.1
Sept. 27	Oct. 6	50	20	.40	26	.10	48	16		.0	217	23	3.3	4.0	236	4.1
Oct. 7	Oct. 16	20	26	1.30	23	Tr.	55	21	15	.0	246	28	4.4	3.2	269	3.4
Oct. 17	Oct. 27	15	29	1.94	26	Tr.	52	19	20	.0	229	29	.4	3.3	248	3.3
Oct. 28	Nov. 6	20	16	.80	27	Tr.	58	20	11	.0	255	29	1.8	4.6	277	3.7
Nov. 7	Nov. 16	10	8.4	.84	17	Tr.	60	19	14	.0	263	28	2.2	3.5	285	3.5
Nov. 17	Nov. 26	20	17	.85	15	.05	64	20	16	.0	262	33	2.6	3.8	281	3.6
Nov. 27	Dec. 6	25	20	.80	17	.04	51	20	15	.0	240	33	.9	3.8	258	4.0
Dec. 7	Dec. 16	15	13	.87	21	.10	62	22	17	.0	273	37	4.4	3.8	309	3.7
Dec. 17	Dec. 26	5.0	2.8	.56	13	.10	64	26	16	.0	309	40	4.8	4.0	311	4.3
Dec. 27	Jan. 5	80	56	.70	12	.20	51	17	13	.0	207	.	4.4	3.1	228	4.2
Jan. 6	Jan. 15	20	22	1.10	9.2	.08	47	17	9.7	.0	175	.	5.2	2.5	193	4.4
Jan. 16	Jan. 26	75	71	.95	15	Tr.	42	13	13	.0	167	29	3.6	2.3	193	4.9
Jan. 27	Feb. 5	5.0	4.0	.80	11	.05	61	19	.....	.0	258	31	5.2	3.9	260	4.5
Feb. 6	Feb. 15	80	68	.85	6.4	.05	58	15	14	.0	221	46	5.2	4.8	242	4.2
Feb. 16	Feb. 26	30	35	1.17	4.6	.10	24	6.6	11	.0	87	21	5.8	2.2	119	5.7
Feb. 27	Mar. 7	70	69	.99	9.8	.25	26	9.6	14	.0	...	35	4.6	2.2	151	5.3
Mar. 8	Mar. 19	65	54	.83	14	.18	32	12	12	.0	..	21	3.8	8.8	178	4.7
Mar. 20	Mar. 29	30	37	1.24	12	.15	37	9.4	16	.0	149	26	2.6	2.7	175	4.6
Mar. 30	Apr. 8	135	84	.62	15	Tr.	41	14	9.9	.0	175	29	2.8	2.3	203	4.7
Apr. 9	Apr. 18	30	25	.83	11	.03	53	16	.....	.0	213	34	2.6	2.7	246	4.0
Apr. 19	Apr. 28	10	Tr.	.....	3.0	.05	54	19	8.1	.0	210	46	.6	3.9	250	3.6
Apr. 29	May 8	10	Tr.	.....	3.0	.05	51	20	8.6	.0	230	35	Tr.	3.8	241	3.6
May 9	May 18	10	Tr.	.....	4.0	.01	48	21	11	.0	226	33	.5	3.4	241	3.3
May 19	May 28	95	98	1.03	5.8	.18	...	17	9.8	.0	204	32	3.0	4.2	225	3.4
May 29	June 8	55	57	1.04	11	.02	43	16	8.8	.0	207	.....	2.2	3.4	230	3.7
June 9	June 18	140	174	1.24	14	.02	47	14	7.0	.0	179	29	4.8	1.9	215	5.4
June 19	June 28	80	124	1.55	10	.05	48	13	9.8	.0	209	28	4.2	2.6	244	5.0
June 29	July 9	235	214	.91	15	.15	49	11	15	.0	201	22	8.0	2.9	230	4.5
July 10	July 19	390	356	.91	20	.48	38	11	6.4	.0	145	22	3.1	..	179	6.3
July 20	July 29	105	108	1.03	14	.05	43	13	12	.0	189	22	2.8	2.5	207	6.4
July 30	Aug. 8	65	58	.89	15	.01	55	15	15	.0	234	27	4.4	4.0	248	4.8
Aug. 9	Aug. 18	140	154	1.10	20	.20	40	13	8.6	.0	166	22	2.2	2.8	192	5.2
Aug. 19	Aug. 28	50	62	1.24	10	.05	42	14	9.1	.0	198	23	2.3	3.3	213	4.5
Aug. 29	Sept. 7	50	53	1.06	20	.15	51	14	11	.0	201	29	1.6	2.5	228	4.6
Sept. 8	Sept. 17	10	Tr.	.....	13	.18	57	18	10	.0	253	31	1.9	3.8	253	3.8
Mean		64	61	.97	14	.09	48	16	12	.0	209	30	3.1	3.4	228	.....
Per ct. of anhydrous residue		.....	.....	.....	6.1	[c] 1	20.9	7.0	5.2	44.8	.....	13.0	1.4	1.5	...	....

[a] Analyses September 6, 1906, to February 15, 1907, by W. M. Barr; February 16 to 26, 1907, by H. S. Spaulding; February 27 to September 17, 1907, by Walton Van Winkle.

[b] Abnormal; computed as HCO_3 in the average.

[c] Fe_2O_3.

Mineral analyses of water from Chattahoochee River at West Point, Ga.[a]

[Parts per million, unless otherwise stated.]

Date (1906–7). From—	To—	Turbidity.	Suspended matter.	Coefficient of fineness.	Total iron (Fe).	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.	Mean gage height (feet).
Oct. 20	Oct. 29	85	50	0.59	.....	16	1.0	6.6	1.2	.....	0.0	24	.....	0.0	2.0	50	4.2
Oct. 30	Nov. 8	45	25	.56	.....	30	.6	3.6	.8	.....	.0	19	.....	.4	2.5	60	3.4
Nov. 9	Nov. 18	65	37	.57	.....	20	.20	5.7	Tr.	.....	.0	22	.....	.4	1.5	54	3.5
Nov. 19	Nov. 29	70	24	.34	.....	26	.7	6.8	1.6	.....	.0	27	.....	.6	3.0	71	4.1
Nov. 30	Dec. 9	60	37	.62	.....	30	.8	6.0	2.8	.....	.0	24	.....	.7	2.8	77	3.3
Dec. 10	Dec. 19	55	34	.62	.....	32	.5	6.4	2.4	.....	.0	29	.....	.4	3.0	81	4.1
Dec. 21	Jan. 1	130	96	.74	.....	32	.9	3.9	Tr.	.....	.0	15	.....	.7	1.5	60	4.8
Jan. 2	Jan. 11	85	65	.76	.....	24	.7	2.3	.8	.....	.0	.....	.....	.8	2.5	55	5.3
Jan. 12	Jan. 21	25	14	.56	.....	17	.10	4.7	.8	.....	.0	17	.....	.8	3.5	59	3.7
Jan. 22	Jan. 31	15	9.0	.60	.....	24	.30	7.4	1.6	.....	.0	29	.....	.5	3.5	59	3.5
Feb. 1	Feb. 10	220	169	.77	.....	33	1.2	3.6	1.6	.....	.0	.....	.....	.4	1.8	53	7.2
Feb. 11	Feb. 26	55	42	.76	.....	18	.9	4.8	Tr.	.....	.0	15	.....	.3	.....	56	3.8
Feb. 27	Mar. 8	260	205	.79	.....	25	1.3	4.4	Tr.	.....	.0	15	.....	.3	1.5	53	7.7
Mar. 9	Mar. 18	290	166	.57	.....	24	.9	5.6	Tr.	.....	.0	20	.....	.4	2.5	53	3.8
Mar. 19	Mar. 28	30	26	.87	.....	11	1.0	6.4	Tr.	.....	.0	22	.....	.2	2.5	40	3.6
Mar. 29	Apr. 7	285	264	.92	.....	28	1.4	6.8	Tr.	.....	.0	22	.....	.4	3.0	59	3.5
Apr. 8	Apr. 17	190	220	1.16	.....	27	1.1	2.0	Tr.	.....	.0	9.8	.....	1.6	1.5	40	3.7
Apr. 18	Apr. 27	185	175	.95	.....	18	1.0	2.5	Tr.	.....	.0	9.8	.....	1.3	2.0	33	5.9
Apr. 28	May 7	185	165	.89	.....	16	1.3	3.5	.8	.....	.0	12	.....	1.1	1.5	34	4.6
May 8	May 18	350	279	.80	16	22	.03	4.9	1.1	8.8	[b] 8.4	13	4.8	.9	.....	57	5.1
May 19	May 28	115	76	.66	7.9	23	.03	5.2	1.9	9.2	[b] 8.4	21	5.0	.9	1.3	65	3.6
May 29	June 7	260	166	64	10	14	.03	3.0	.6	10	.0	26	4.0	1.2	1.7	47	3.7
June 8	June 17	130	91	.70	2.4	16	.03	3.2	1.1	7.2	[b] 3.6	21	3.5	.0	1.0	45	3.1
June 18	June 27	120	81	.67	5.8	11	.00	5.1	1.2	6.7	.0	16	7.6	.7	1.7	42	2.8
June 28	July 7	340	246	.72	13	12	.00	4.9	.7	7.0	[b] Tr.	27	4.0	1.1	2.0	45	3.2
July 9	July 18	450	448	1.00	35	9.0	.00	4.3	.9	7.6	.0	28	3.0	1.0	1.2	36	3.0
July 19	July 28	325	214	.66	12	13	.00	4.0	1.1	8.1	.0	24	3.8	1.1	1.2	40	2.6
July 29	Aug. 7	375	289	.77	21	12	.03	6.0	1.3	9.4	.0	37	6.6	1.2	4.8	63	2.7
Aug. 8	Aug. 17	400	220	.55	10	14	Tr.	3.2	1.0	7.9	.0	24	4.0	1.1	1.8	47	2.6
Aug. 18	Aug. 27	375	242	.64	6.6	15	Tr.	4.2	.6	6.3	.0	28	4.2	1.1	2.0	48	2.6
Aug. 28	Sept. 6	225	121	.54	3.7	17	Tr.	4.9	.5	6.5	.0	27	4.8	1.0	1.8	60	2.0
Sept. 17	Sept. 26	155	129	.83	5.2	12	Tr.	5.1	.8	6.6	.0	27	4.3	.7	1.3	46	2.6
Sept. 27	Oct. 8	185	100	.54	12	18	Tr.	4.9	.4	9.0	.0	29	4.1	1.0	1.8	54	2.5
Oct. 9	Oct. 18	140	98	.70	4.4	8.9	Tr.	5.7	1.0	5.8	.0	27	3.5	.6	1.7	42	2.1
Mean		185	136	.71	.....	20	.47	4.8	.8	7.7	.0	23	4.5	.7	2.1	52	.....
Per ct. of anhydrous residue		.....	.....	.....	.....	38.0	[c] 1.3	9.1	1.6	14.6	21.5	.....	8.5	1.4	4.0	.....	.....

[a] Analyses October 20, 1906, to May 7, 1907, by Jas. R. Evans; May 8 to October 18, 1907, by R. B. Dole, Chase Palmer, and W. D. Collins.

[b] Abnormal; computed as HCO_3 in the average.

[c] Fe_2O_3.

Mineral analyses of water from Chippewa River near Eau Claire, Wis.[a]

[Parts per million, unless otherwise stated.]

Date (1906–7). From—	To—	Turbidity.	Suspended matter.	Coefficient of fineness.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.	Mean gage height (feet).
Sept. 14	Sept. 23	5	Tr.	.....	24	0.20	11	3.7	8.4	0.0	45	12	Tr.	3.2	111	6.4
Sept. 24	Oct. 3	10	Tr.	.....	11	.30	12	4.0	7.1	.0	44	9.0	1.8	2.1	98	6.1
Oct. 4	Oct. 13	5	Tr.	.....	5.8	.20	12	5.1	9.4	.0	45	14	Tr.	1.2	98	5.0
Oct. 14	Oct. 23	5	4.8	0.96	16	.15	13	6.3	7.0	.0	59	19	Tr.	1.3	103	4.9
Oct. 24	Nov. 2	5	9.6	1.92	15	.15	10	5.2	8.1	.0	39	16	Tr.	2.9	102	7.8
Nov. 3	Nov. 12	5	a4.8	.96	12	Tr.	16	5.2	8.6	.0	41	13	Tr.	2.3	109	6.8
Nov. 13	Nov. 22	5	Tr.	.....	12	Tr.	12	4.2	.....	.0	33	14	Tr.	1.5	87	6.4
Nov. 23	Dec. 2	15	6.4	.43	16	Tr.	10	.....	7.5	.0	39	17	.0	.9	93	6.5
Dec. 3	Dec. 13	10	4.8	.48	17	.40	12	4.2	9.2	.0	40	19	.0	1.2	94	5.4
Dec. 14	Dec. 25	5	2.8	.56	15	.30	14	4.9	10	.0	53	17	.0	2.0	101	5.2
Dec. 26	Jan. 4	5	Tr.	.....	15	.25	14	5.7	7.3	.0	36	.....	.9	1.5	97	5.0
Jan. 5	Jan. 17	5	Tr.	.....	10	.25	16	5.3	.....	.0	58	13	Tr.	.....	94	4.9
Jan. 18	Jan. 27	10	6.4	.64	12	.40	15	5.8	13	.0	61	9.9	.2	2.7	96	.....
Jan. 28	Feb. 7	5	Tr.	.....	15	.25	17	4.8	5.6	.0	70	12	.8	.4	109	.....
Feb. 8	Feb. 18	5	4.0	.80	15	.25	17	8.5	11	.0	66	10	1.4	.6	97	.....
Feb. 19	Feb. 28	5	Tr.	.....	15	.25	17	4.1	8.7	.0	65	12	1.8	1.6	95	.....
Mar. 1	Mar. 10	5	Tr.	.....	18	.6	19	6.6	7.6	.0	68	15	1.2	1.5	104	.....
Mar. 11	Mar. 20	5	3.2	.64	12	.30	14	.....	9.1	.0	60	16	2.1	2.3	100	5.1
Mar. 21	Mar. 31	20	34	1.70	4.6	.37	.....	2.8	5.4	.0	25	15	1.2	1.5	59	11.2
Apr. 1	Apr. 10	10	10	1.00	6.8	.19	6.2	3.7	5.2	.0	.....	18	1.1	.4	58	11.2
Apr. 11	Apr. 20	5	7.6	1.52	6.8	.15	11	2.4	8.5	.0	22	14	.9	.1	72	7.9
Apr. 21	Apr. 30	Tr.	Tr.	.....	12	.18	9.8	3.7	4.6	.0	29	17	Tr.	.7	73	7.0
May 1	May 12	Tr.	Tr.	.....	9.6	.24	.....	5.2	4.4	.0	39	16	Tr.	Tr.	72	7.3
May 13	May 22	5	Tr.	.....	7.4	.18	8.2	2.3	.....	.0	28	11	Tr.	.1	63	8.7
May 23	June 1	5	Tr.	.....	7.0	.19	7.0	2.4	4.9	.0	28	9.9	Tr.	2.4	89	8.2
June 2	June 11	5	Tr.	.....	5.8	.16	10	3.0	4.3	.0	38	8.7	.8	Tr.	68	6.6
June 12	June 21	5	Tr.	.....	5.2	.25	10	4.3	5.9	.0	46	15	Tr.	.2	87	6.0
June 22	July 1	5	Tr.	.....	10	.18	15	.....	9.5	.0	56	14	1.2	.8	90	6.0
July 3	July 12	10	9.2	.92	9.8	.20	13	4.4	7.6	.0	45	15	1.0	.2	81	6.3
July 13	July 22	5	Tr.	.....	10	.30	14	.....	7.3	.0	.....	10	.5	.3	84	5.1
July 23	Aug. 2	7	Tr.	.....	12	.21	17	.....	10	.0	59	9.9	Tr.	.3	93	4.8
Aug. 3	Aug. 13	5	Tr.	.....	14	.15	16	6.9	8.6	.0	61	.....	4.4	.3	90	.45
Aug. 14	Aug. 23	20	22	1.10	13	.19	16	.....	11	.0	55	12	Tr.	Tr.	94	.47
Aug. 24	Sept. 2	5	Tr.	.....	11	.09	13	5.2	13	.0	59	12	.4	.3	88	.44
Sept. 3	Sept. 12	5	Tr.	.....	14	.12	16	6.1	11	.0	72	15	.3	1.0	108	.42
Mean		7.0	3.7	.97	12	.22	13	4.7	8.1	.0	48	14	.6	1.1	90	.....
Per ct. of anhydrous residue		.....	.....	.....	15.5	b.4	16.8	6.1	10.5	30.5	.....	18.0	.8	1.4	.....	.....

a Analyses September 14, 1906, to February 7, 1907, by W. M. Barr; February 8 to February 28, 1907, by H. S. Spaulding; March 1 to September 12, 1907, by Walton Van Winkle.

b Fe_2O_3.

Mineral analyses of water from Colorado River at Austin, Tex.[a]

[Parts per million, unless otherwise stated.]

Date (1905–6). From—	To—	Suspended matter.	Silica (SiO_2).	Oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Total dissolved solids.	Mean gage height (feet).
Aug. 1	Aug. 10	2,480	19	3.6	53	7.9	30	1.8	0.0	177	41	34	300	2.5
Aug. 11	Aug. 20	28	23	4.0	58	12	42	3.6	.0	199	52	37	322	1.4
Aug. 21	Aug. 30	22	28	1.4	53	15	45	5.3	.0	171	38	47	316	.9
Aug. 31	Sept. 9	24	26	2.8	69	16	58	3.6	.0	220	39	44	296	.9
Sept. 10	Sept. 18	144	27	1.4	56	14	48	7.5	.0	212	45	53	326	1.3
Sept. 22	Sept. 29	124	25	2.6	57	15	103	7.0	.0	156	110	137	498	1.7
Sept. 30	Oct. 9	276	30	1.0	73	15	52	4.3	.0	187	60	98	432	1.4
Oct. 10	Oct. 19	302	20	1.8	49	10	72	11	.0	175	34	32	244	1.7
Oct. 20	Oct. 29	742	27	2.0	52	10	49	8.3	.0	161	37	40	248	1.8
Oct. 31	Nov. 8	148	21	2.4	47	9.1	.....	.....	.0	174	29	32	226	1.0
Nov. 10	Nov. 19	466	22	1.8	54	13	.....	.....	.0	173	33	38	252	1.9
Nov. 20	Nov. 29	46	19	2.4	47	12	.....	.....	.0	173	34	41	246	1.1
Nov. 30	Dec. 9	60	17	3.2	46	15	30	3.6	.0	197	24	49	268	1.0
Dec. 10	Dec. 19	26	14	1.8	47	17	31	4.4	.0	201	21	44	280	1.1
Dec. 20	Dec. 29	18	15	1.2	47	19	27	1.2	.0	223	18	48	294	1.1
Dec. 30	Jan. 8	50	10	2.0	53	20	32	4.3	.0	238	26	56	366	1.1
Jan. 9	Jan. 18	36	8.8	4.6	54	21	34	3.8	.0	238	28	53	330	.9
Jan. 19	Jan. 28	0	9.0	2.8	49	21	34	4.0	.0	228	29	60	324	1.0
Jan. 29	Feb. 7	22	10	3.2	48	21	38	3.5	.0	220	24	55	298	.9
Feb. 8	Feb. 17	76	14	3.4	51	22	35	3.4	.0	219	29	48	290	1.1
Feb. 18	Feb. 27	10	12	3.6	47	22	34	3.6	.0	214	25	51	306	1.1
Feb. 28	Mar. 9	38	9.0	1.2	48	24	35	4.0	.0	218	42	66	324	.9
Mar. 10	Mar. 19	42	.....	1.6	48	23	19	4.0	.0	221	39	59	320	.9
Mar. 20	Mar. 29	14	8.8	1.8	49	24	.....	.....	.0	223	35	86	336	1.2
Mar. 30	Apr. 8	94	14	2.4	52	21	39	.....	.0	239	35	56	338	1.4
Apr. 9	Apr. 18	114	11	2.6	59	25	44	.....	.0	217	46	75	320	1.4
Apr. 19	Apr. 28	82	14	3.0	48	24	64	.....	.0	204	80	79	402	2.7
Apr. 29	May 8	78	14	6.4	56	24	53	3.5	.0	205	89	75	426	1.4
May 9	May 18	90	18	6.8	68	24	77	4.9	.0	180	112	113	536	1.2
May 19	May 28	600	14	3.6	45	21	90	4.4	.0	184	102	134	550	2.6
May 29	June 7	1,256	19	4.8	57	8.7	51	4.3	.0	154	37	67	294	3.3
June 8	June 17	844	35	7.0	62	17	36	4.2	[b]18	151	30	55	270	3.7
June 18	June 27	484	21	2.8	41	13	51	9.9	.0	166	43	57	308	1.8
June 28	July 7	400	17	4.4	40	6.8	25	8.9	.0	160	18	26	220	2.5
July 8	July 17	1,508	13	4.6	45	10	31	6.9	.0	177	28	52	268	4.9
July 18	July 27	1,882	21	4.4	40	6.5	11	9.2	.0	133	14	24	178	5.3
Mean		351	18	3.1	52	17	44	5.1	.0	195	42	59	321	.....
Per ct. of anhydrous residue		.....	5.4	.9	15.5	5.1	13.1	1.5	28.5	.....	12.5	17.5	.....	.....

[a] Analyses by W. H. Heileman.
[b] Abnormal; computed as HCO_3 in the average.

Mineral analyses of water from Cumberland River near Nashville, Tenn.[a]

[Parts per million, unless otherwise stated.]

Date (1906–7). From—	Date (1906–7). To—	Turbidity.	Suspended matter.	Coefficient of fineness.	Total iron (Fe).	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.	Mean gage height (feet).
Oct. 24	Nov. 3	75	58	0.77	.....	29	4.0	33	3.2	.....	0.0	115	.....	0.6	2.0	139	8.8
Nov. 4	Nov. 13	28	15	.54	.....	26	.20	26	1.2	.....	.0	90	.....	.7	3.5	112	8.0
Nov. 14	Nov. 23	30	15	.50	.....	27	.30	24	1.2	.....	.0	76	.....	.8	3.0	109	18.1
Nov. 24	Dec. 3	35	16	.46	.....	28	.20	24	2.0	.....	.0	81	.....	.8	2.5	106	17.1
Dec. 4	Dec. 13	50	37	.74	.....	29	.20	22	2.8	.....	.0	83	.....	.6	2.8	111	9.5
Dec. 14	Dec. 23	75	50	.67	.....	28	.30	27	3.6	.....	.0	85	.....	.5	3.0	114	20.0
Dec. 24	Jan. 2	135	108	.80	.....	33	.20	27	2.8	.....	.0	85	.....	.8	1.0	128	21.3
Jan. 3	Jan. 12	150	132	.88	.....	22	.30	23	.....	.....	.0	81	.....	.6	1.8	110	25.0
Jan. 13	Jan. 22	60	41	.68	.....	31	.10	26	3.6	.....	.0	93	.....	1.0	1.7	118	15.1
Jan. 23	Feb. 1	75	46	.61	.....	20	.40	21	4.4	.....	.0	78	.....	.6	2.0	106	18.7
Feb. 2	Feb. 11	65	40	.62	.....	13	.30	26	3.6	.....	.0	90	.....	.4	2.0	107	14.2
Feb. 12	Feb. 23	90	78	.87	.....	21	.30	22	3.2	.....	.0	83	.....	.3	1.0	97	11.4
Feb. 24	Mar. 5	180	156	.87	.....	31	.30	23	3.6	.....	.0	.....	.....	.4	1.2	114	29.8
Mar. 6	Mar. 16	350	322	.92	.....	31	.10	22	.....	.....	.0	78	.....	.5	1.0	112	28.7
Mar. 17	Mar. 26	110	96	.87	.....	25	.30	24	.....	.....	.0	81	.....	.4	2.0	112	22.1
Mar. 27	Apr. 5	70	62	.88	.....	15	.30	27	4.0	.....	.0	93	.....	.5	2.0	107	10.3
Apr. 6	Apr. 15	135	130	.96	.....	27	.10	20	5.2	.....	.0	78	.....	.2	1.5	100	18.7
Apr. 16	Apr. 25	45	48	1.07	.....	9.6	Tr.	17	7.6	.....	.0	76	.....	1.8	1.5	87	11.6
Apr. 26	May 5	95	119	1.25	.....	12	.20	18	.....	.....	.0	78	.....	1.6	2.0	91	10.3
May 6	May 15	75	63	.84	.....	11	.20	18	6.4	.....	.0	73	.....	1.1	.....	88	24.3
May 15	May 24	85	.....	.....	.....	20	.30	30	3.2	5.7	.0	98	16	2.7	1.4	128	14.0
May 25	June 3	80	48	.60	.....	24	.20	.....	4.5	2.9	.0	110	14	2.0	1.5	150	10.2
June 4	June 13	425	318	.74	.....	20	.8	31	4.1	7.9	.0	100	16	4.3	2.4	146	16.8
June 14	June 23	110	85	.77	.....	17	.35	22	4.1	5.7	.0	82	18	3.2	1.4	121	14.4
June 24	July 3	245	140	.57	.....	14	.24	29	4.7	6.0	.0	115	16	1.9	1.8	138	9.3
July 4	July 14	100	60	.60	.....	15	.25	32	4.5	8.9	.0	113	14	1.4	2.4	140	8.2
July 15	July 25	30	.....	.....	.....	12	.25	31	5.8	11	.0	.....	14	.9	4.8	140	8.1
July 26	Aug. 4	70	38	.54	.....	13	.12	32	.....	8.6	.0	113	9.7	1.7	2.0	122	7.8
Aug. 5	Aug. 14	195	185	.95	.....	7.8	.03	33	.....	13	.0	118	14	1.7	3.3	127	8.0
Aug. 15	Aug. 24	110	52	.47	.....	5.2	.20	36	1.8	15	.0	115	20	.6	2.0	135	7.5
Aug. 25	Sept. 3	80	67	.84	.....	8.2	.20	33	.....	10	.0	102	14	1.6	1.5	125	7.8
Sept. 5	Sept. 14	250	130	.52	.....	14	.45	26	.....	8.2	.0	95	17	.8	2.0	128	8.2
Sept. 25	Oct. 13	450	224	.49	12	24	1.3	26	1.4	11	.0	90	10	1.6	1.8	127	8.8
Oct. 14	Oct. 24	215	82	.38	6.1	28	1.0	24	3.0	16	[b]Tr.	95	13	1.3	3.6	140	8.0
Oct. 25	Nov. 3	45	41	.91	3.0	19	.9	27	0.9	14	[b]Tr.	99	12	1.0	2.4	130	7.4
Mean		126	94	.74	.....	20	.42	26	3.6	9.6	.0	92	14	1.2	2.1	119	.....
Per ct. of anhydrous residue		....	....	.....	.....	16.4	c.5	21.3	2.9	7.8	37.0	.....	11.4	1.0	1.7	.....	.....

[a] Analyses October 24, 1906, to May 15, 1907, by Jas. R. Evans; May 15 to September 14, 1907, by Waltop Van Winkle; September 25 to November 3, 1907, by R. B. Dole, Chase Palmer, and W. D. Collins.
[b] Abnormal, computed as HCO_3 in the average.
[c] Fe_2O_3.

Mineral analyses of water from Cumberland River near Kuttawa, Ky.[a]

[Parts per million, unless otherwise stated.]

Date (1907–8). From—	To—	Turbidity.	Suspended matter.	Coefficient of fineness.	Total iron (Fe).	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.	Mean gage height (feet).[b]
Jan. 11	Jan. 20	45	29	0.64	.....	29	0.20	27	7.2	.....	0.0	110	.....	0.6	2.7	147	17.1
Jan. 21	Feb. 2	95	68	.72	.....	18	.40	24	3.6	.....	.0	78	.....	1.0	1.7	.....	24.2
Feb. 3	Feb. 12	70	38	.54	.....	25	.30	24	3.6	.....	.0	85	.....	.4	1.5	118	16.3
Feb. 13	Feb. 23	170	136	.80	.....	25	.10	23	.....	.....	.0	85	.....	.6	1.5	104	11.7
Feb. 24	Mar. 7	320	260	.81	.....	31	.20	22	4.8	.....	.0	.....	.....	.3	1.8	108	36.8
Mar. 8	Mar. 17	290	217	.75	.....	38	.40	24	3.2	.....	.0	80	.....	.8	1.5	122	33.4
Mar. 18	Mar. 27	180	164	.91	.....	23	.20	22	5.6	.....	.0	.....	.....	.5	2.5	108	27.5
Mar. 28	Apr. 6	85	60	.71	.....	18	.20	26	.....	.....	.0	102	.....	.4	3.0	124	9.7
Apr. 7	Apr. 16	35	20	.57	.....	10	.10	27	4.0	.....	.0	83	.....	.9	1.5	96	21.1
Apr. 17	Apr. 26	100	85	.85	.....	7.6	.20	26	3.6	.....	.0	80	.....	2.2	2.0	91	10.9
Apr. 27	May 6	95	106	1.12	.....	8.4	Tr.	25	4.8	.....	.0	80	.....	2.9	4.0	94	9.9
May 6	May 15	340	470	1.38	.....	11	.6	27	4.2	8.2	.0	99	7.1	5.0	1.0	112	34.7
May 17	May 26	130	174	1.34	.....	17	.30	31	4.6	7.2	.0	118	7.2	3.0	4.0	131	16.6
May 27	June 5	120	134	1.12	.....	11	.40	33	5.4	4.4	.0	121	13	1.5	4.0	137	10.1
June 6	June 16	490	796	1.62	.....	17	.8	25	3.1	.....	.0	101	6.9	1.7	2.0	122	22.3
June 17	June 28	180	150	.83	.....	14	.40	27	3.4	8.0	.0	105	6.7	2.5	3.5	123	11.1
June 29	July 8	80	71	.89	.....	16	.20	31	3.9	.....	.0	126	8.2	1.9	3.5	137	5.5
July 9	July 18	142	107	.75	.....	12	.20	34	4.2	9.1	.0	.....	8.1	1.5	4.0	135	4.3
July 19	July 29	20	38	1.90	1.0	17	.07	34	4.8	8.2	3.6	111	8.7	1.4	3.9	136	3.7
July 30	Aug. 8	25	35	1.40	1.1	27	.06	36	5.7	10	2.4	124	8.7	1.8	4.2	153	2.8
Aug. 9	Aug. 22	200	123	.62	6.1	24	.26	35	4.6	9.5	2.4	123	8.6	1.6	3.8	152	4.1
Sept. 2	Sept. 11	220	119	.54	6.6	19	.24	35	5.6	11	4.8	112	11	1.4	5.0	149	3.0
Sept. 12	Sept. 21	350	258	.74	12	26	1.2	28	4.6	8.5	Tr.	100	13	3.8	3.0	145	6.9
Sept. 22	Oct. 1	300	224	.75	12	19	.9	21	3.6	6.6	Tr.	73	9.0	3.5	4.2	108	6.2
Oct. 2	Oct. 11	220	170	.77	10	16	.52	29	4.1	6.4	Tr.	96	10	2.2	3.0	125	4.1
Oct. 12	Oct. 21	200	189	.95	11	7.4	.24	28	4.0	6.9	7.2	82	10	.8	3.0	107	4.9
Oct. 22	Oct. 31	150	82	.55	6.6	16	.35	31	4.7	9.4	Tr.	115	10	2.4	5.0	133	1.9
Nov. 1	Nov. 10	90	74	.82	3.5	9.2	.11	34	5.2	7.1	4.8	107	11	2.2	4.8	129	4.0
Nov. 11	Nov. 21	270	287	1.06	12	12	.32	31	4.8	9.0	4.8	99	13	2.0	3.8	128	9.3
Nov. 22	Dec. 1	220	268	1.22	10	13	.54	30	3.7	6.9	Tr.	102	11	2.0	3.0	141	13.0
Dec. 2	Dec. 11	170	112	.66	3.3	17	.04	22	3.4	8.5	.0	.....	10	2.4	2.4	105	7.5
Dec. 12	Dec. 21	70	71	1.02	2.2	14	.04	32	2.2	5.4	.0	106	11	2.3	2.4	126	7.2
Dec. 22	Dec. 31	260	253	.97	7.9	15	.15	34	4.6	8.2	.0	110	12	3.0	2.2	137	14.8
Jan. 1	Jan. 11	240	238	.99	8.0	15	.10	27	3.1	5.7	.0	84	8.9	2.0	2.2	111	.....
Mean		176	165	.92	.....	18	.30	28	4.3	7.8	.9	100	9.7	1.8	3.0	124	.....
Per ct. of anhydrous residue		.....	.....	.....	.....	14.6	c 4	22.8	3.5	6.3	40.6	.....	7.9	1.5	2.4	.....	.....

[a] Analyses January 11 to May 6, 1907, by Jas. R. Evans; May 6 to July 18, 1907, by W. D. Collins; July 19, 1907, to January 11, 1908, by R. B. Dole, Chase Palmer and W. D. Collins.

[b] Gaging station at Clarkesville, Tenn., 70 miles above.

[c] Fe_2O_3.

Mineral analyses of water from Dan River at South Boston, Va.[a]

[Parts per million, unless otherwise stated.]

Date (1906–7.) From—	To—	Turbidity.	Suspended matter.	Coefficient of fineness.	Total iron (Fe).	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.	Mean gage height (feet).
Sept. 3	Sept. 13	210	126	0.60	8.9	26	1.4	6.0	2.8	4.2	0.0	41	1.3	Tr.	2.4	75	3.2
Oct. 1	Oct. 11	260	175	.67	9.8	31	2.1	5.2	1.8	7.6	.0	34	2.5	0.8	2.6	82	4.2
Oct. 12	Oct. 21	43	42	.98	2.4	50	.7	6.0	2.2	8.5	.0	39	2.6	Tr.	3.1	100	4.3
Oct. 22	Oct. 31	31	25	.81	1.4	23	.6	5.2	2.0	7.6	.0	36	2.3	Tr.	2.4	61	4.8
Nov. 1	Nov. 11	17	33	1.94	1.0	17	.07	5.2	1.6	5.2	.0	34	2.8	.6	3.4	52	2.5
Nov. 12	Nov. 21	230	181	.79	8.4	21	1.3	4.8	1.2	5.4	.0	30	3.3	1.6	2.7	67	2.7
Nov. 22	Dec. 1	28	131	.47	2.0	16	.3	5.6	1.4	6.3	.0	32	4.3	.6	2.6	54	2.3
Dec. 2	Dec. 12	21	76	3.62	3.5	18	.28	5.4	1.8	4.9	.0	35	1.6	.5	3.0	50	2.3
Dec. 13	Dec. 23	220	664	3.00	16	26	2.2	4.4	1.6	6.8	.0	33	4.3	1.1	3.4	78	2.6
Dec. 24	Dec. 31	350	742	2.12	24	23	1.8	4.6	1.8	6.0	.0	29	4.3	1.6	2.9	69	3.5
Jan. 3	Jan. 13	55	525	9.54	10	16	.35	4.8	1.8	6.2	.0	31	2.8	1.6	3.4	54	4.5
Jan. 20	Jan. 29	110	815	7.41	9.5	21	1.0	5.6	2.0	6.5	.0	40	3.1	Tr.	4.1	75	2.7
Jan. 30	Feb. 9	90	215	2.39	6.5	23	1.0	6.2	2.0	6.2	.0	40	3.5	.2	3.6	77	2.8
Feb. 10	Feb. 19	175	324	1.85	11	23	2.2	5.4	1.0	6.5	.0	25	4.1	2.1	2.9	75	3.1
Feb. 20	Mar. 2	110	209	1.90	8.0	25	2.2	6.0	1.2	6.6	.0	24	5.8	1.8	2.5	84	2.9
Mar. 3	Mar. 12	380	677	1.78	9.0	24	2.4	5.8	.6	7.7	.0	26	4.0	1.9	3.1	86	5.1
Mar. 13	Mar. 24	47	231	4.90	5.3	18	.33	7.8	.8	6.8	.0	28	5.3	2.4	4.1	66	4.6
Mar. 25	Apr. 3	27	45	1.67	1.4	16	.08	6.8	.8	9.5	[b]16	3.0	5.1	.0	5.3	64	2.6
Apr. 4	Apr. 13	225	150	.67	10	28	1.0	6.0	1.1	9.4	.0	40	3.6	3.0	3.1	88	4.9
Apr. 14	Apr. 23	38	44	1.16	2.3	18	.24	5.6	1.6	6.3	.0	29	2.5	1.8	3.4	55	2.7
Apr. 24	May 2	98	110	1.12	6.5	31	1.1	5.6	1.0	8.2	.0	30	2.8	1.8	4.2	86	4.2
Mean		132	264	2.35	7.5	24	1.1	5.6	1.5	6.8	.0	33	3.4	1.1	3.2	71	....
Per ct. of anhydrous residue		.....	.....	.....	.....	38.0	[c]2.5	8.9	2.4	10.7	25.3	.....	5.4	1.7	5.1	.....	.....

[a] Analyses September 3 to October 31, 1906, by R. B. Dole; November 1, 1906, to April 3, 1907, by R. B. Dole and M. G. Roberts; April 4 to May 2, 1907, by Chase Palmer and M. G. Roberts.

[b] Abnormal; computed as HCO_3 in the average.

[c] Fe_2O_3.

Mineral analyses of water from Delaware River at Lambertville, N. J.[a]

[Parts per million, unless otherwise stated.]

Date (1906-7.)		Turbidity.	Suspended matter.	Coefficient of fineness.	Total iron (Fe).	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.	Mean gage height (feet).
From—	To—																
Sept. 8	Sept. 17	2	.....	.....	....	22	0.20	14	4.4	5.7	0.0	59	9.9	0.5	2.6	94	2.80
Sept. 18	Sept. 26	13	15	1.15	0.1	12	Tr.	16	5.2	6.9	.0	63	13	.5	3.1	87	2.64
Sept. 28	Oct. 7	85	62	.73	.3	17	.20	15	3.8	5.7	.0	61	17	.5	2.8	94	3.17
Oct. 8	Oct. 17	5	5	1.00	.1	13	Tr.	16	3.2	5.5	.0	52	15	.6	3.2	85	3.16
Oct. 18	Oct. 29	18	50	2.77	.8	16	Tr.	12	1.6	5.2	.0	38	12	.5	2.8	75	4.67
Oct. 30	Nov. 9	6	6.4	1.07	.1	7.2	Tr.	10	1.8	5.7	.0	37	10	.8	2.6	58	4.74
Nov. 10	Nov. 19	5	2	.40	.1	8.0	.06	10	2.4	5.4	.0	36	14	.7	2.6	61	4.39
Nov. 20	Nov. 29	9	9.2	1.02	.2	6.0	Tr.	7.8	1.0	4.9	.0	28	9.2	.8	1.8	46	5.64
Nov. 30	Dec. 9	3	1.2	.40	Tr.	8.0	Tr.	9.4	2.2	.....	.0	35	11	.8	1.9	55	4.62
Dec. 10	Dec. 19	5	1.4	.28	.2	6.4	.12	9.2	3.4	3.6	.0	....	9.2	1.6	2.6	51	4.92
Dec. 20	Dec. 30	6	5.8	.97	.2	7.6	.11	10	3.6	3.6	.0	37	11	2.0	2.9	58	4.80
Dec. 31	Jan. 9	43	78	1.81	2.1	7.6	.14	9.0	3.0	3.9	.0	.....	.....	1.4	2.4	50	7.12
Jan. 10	Jan. 19	8	10	1.25	.4	5.8	.11	9.0	3.2	3.0	.0	....	9.6	1.6	2.4	47	5.98
Jan. 20	Jan. 30	8	9.2	1.15	.3	6.6	.09	9.5	3.4	3.8	.0	....	11	1.8	2.4	51	5.39
Jan. 31	Feb. 9	3	3.2	1.06	.2	7.2	.14	10	4.0	3.3	.0	35	11	1.6	2.9	57	4.66
Feb. 10	Feb. 19	6	8.8	1.47	.2	6.0	.04	12	4.2	5.8	.0	....	13	1.9	2.6	65	.....
Feb. 20	Mar. 1	12	16	1.33	.1	.....	.06	12	4.0	6.6	.....	.....	11	.5	2.6	76	.....
Mar. 2	Mar. 11	7	7.0	1.00	.3	12	.06	13	4.6	.....	[b]4.3	41	14	2.1	2.9	77	3.75
Mar. 12	Mar. 22	39	96	2.46	1.9	3.0	.05	8.4	2.6	5.7	.0	35	11	1.1	2.6	49	7.19
Apr. 2	Apr. 12	2	5.2	2.60	.3	7.4	.09	8.9	2.9	3.8	.0	....	9.9	1.5	2.6	50	5.20
Apr. 13	Apr. 22	1	2.8	2.80	.2	7.2	.09	9.4	1.9	4.4	.0	32	9.6	1.0	2.2	52	4.89
May 4	May 13	7	15	2.14	.3	8.6	.05	9.7	3.5	5.0	.0	41	9.2	.6	2.2	59	4.94
May 14	May 23	4	12	3.00	.5	11	.07	10	3.0	6.3	.0	41	9.7	1.0	2.6	66	3.34
May 24	June 2	4	12	3.00	.4	7.4	.11	10	3.7	5.7	.0	43	9.7	.7	2.5	62	4.21
June 4	June 13	4	10	2.50	.5	5.6	.10	9.1	3.3	.....	.0	30	10	.7	2.6	52	4.79
June 14	June 23	4	9.0	2.25	.3	3.4	.11	11	3.8	3.8	.0	43	10	.6	3.2	58	3.88
June 25	July 4	9	21	2.33	.4	4.8	.09	12	4.0	5.4	.0	44	12	1.4	3.0	66	4.10
July 5	July 14	90	126	1.40	1.6	.....	.05	14	5.0	.....	.....	....	16	Tr.	3.0	101	3.73
July 15	July 24	65	72	1.11	1.8	14	.13	16	.....	8.8	.0	....	15	1.5	3.0	85	3.52
July 25	Aug. 3	15	41	2.73	1.0	7.2	.04	16	.....	6.9	.0	52	16	1.1	4.0	83	2.57
Aug. 4	Aug. 13	10	45	4.50	.9	11	.04	17	.....	6.6	.0	61	18	1.1	4.0	94	2.29
Aug. 15	Aug. 25	30	63	2.10	1.2	4.8	.04	19	.....	7.9	.0	66	18	1.7	5.4	94	2.32
Aug. 26	Sept. 4	12	31	2.58	.7	11	.06	19	.....	.....	.0	72	19	1.6	4.8	109	2.83
Sept. 5	Sept. 12	12	11	.92	.6	13	.03	17	.....	9.1	.0	66	17	1.5	3.6	101	4.02
Mean		16	26	1.74	.6	9.0	.07	12	3.3	5.4	.0	46	12	1.1	2.9	70	.....
Per ct. of anhydrous residue		....	.....	.....	....	13.1	c.2	17.5	4.8	7.9	33.2	....	17.5	1.6	4.2	....	.....

[a] Analyses September 8 to December 9, 1906, by R. B. Dole; December 10, 1906, to March 22, 1907, by R. B. Dole and M. G. Roberts; April 2 to July 4, 1907, by Chase Palmer and M. G. Roberts; July 5 to September 12, 1907, by R. B. Dole, Chase Palmer, and W. D. Collins.

[b] Abnormal; computed as HCO_3 in the average.

[c] Fe_2O_3.

Mineral analyses of water from Des Moines River at Keosauqua, Iowa.[a]

[Parts per million, unless otherwise stated.]

Date (1906–7). From—	To—	Turbidity.	Suspended matter.	Coefficient of fineness.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.
Sept. 10	Sept. 19	275	216	0.78	35	Tr.	50	21	27	0.0	233	51	2.2	4.5	303
Sept. 20	Sept. 29	425	514	1.21	23	.10	47	12	20	.0	188	40	2.5	4.8	256
Sept. 30	Oct. 9	150	132	.88	23	.10	58	.....	14	.0	233	49	2.2	4.8	294
Oct. 10	Oct. 19	65	46	.71	32	.10	68	34	17	.0	.....	.....	1.8	6.1	368
Oct. 20	Oct. 29	20	24	1.20	31	Tr.	70	30	31	.0	.....	92	.6	8.1	396
Oct. 30	Nov. 8	115	132	1.15	23	.05	64	25	20	.0	.....	65	3.1	5.4	336
Nov. 9	Nov. 18	50	63	1.26	22	.05	71	28	19	.0	272	.....	1.3	3.5	361
Nov. 19	Nov. 28	60	55	.92	17	.05	80	28	26	.0	310	90	1.8	5.1	399
Nov. 29	Dec. 8	85	72	.85	26	.15	74	27	22	.0	315	91	2.0	5.3	407
Dec. 9	Dec. 18	30	24	.80	27	.05	83	28	18	.0	.....	96	3.5	5.5	431
Dec. 19	Dec. 28	5	Tr.	(?)	18	.10	100	38	27	.0	412	107	2.6	8.1	492
Dec. 29	Jan. 7	525	460	.88	34	...	61	22	18	.0	220	83	2.6	4.6	345
Jan. 8	Jan. 17	135	116	.86	20	.9	50	17	13	.0	167	61	4.4	6.5	259
Jan. 18	Jan. 27	235	211	.90	29	1.2	30	10	11	.0	99	52	3.9	4.0	207
Jan. 28	Feb. 8	40	23	.57	18	.45	48	17	16	.0	168	69	1.4	6.5	261
Feb. 10	Feb. 19	220	182	.83	23	.5	65	23	18	.0	231	104	2.2	8.5	346
Feb. 20	Mar. 1	95	94	.99	14	.35	40	13	16	.0	134	61	5.1	4.7	214
Mar. 2	Mar. 12	650	752	1.16	20	1.0	41	14	12	.0	129	60	7.5	5.3	245
Mar. 13	Mar. 22	950	1,063	1.12	23	.9	43	15	22	.0	.....	79	7.3	3.8	258
Mar. 23	Mar. 31	450	566	1.26	18	.6	45	16	18	.0	175	64	4.2	3.3	258
Apr. 2	Apr. 11	300	287	.96	18	.5	55	19	13	.0	218	62	2.6	3.5	288
Apr. 12	Apr. 21	75	99	1.32	15	.10	67	24	17	.0	266	76	4.0	3.9	339
Apr. 22	May 1	35	66	1.89	19	.05	66	30	20	.0	274	89	.5	6.2	386
May 2	May 11	20	.....	.....	11	.15	71	24	20	.0	266	105	Tr.	8.8	383
May 12	May 21	80	106	1.32	5.2	.05	57	27	19	.0	238	94	1.1	9.6	335
May 22	May 31	1,740	1,667	.96	30	1.0	53	19	13	.0	175	82	3.4	3.7	316
June 1	June 10	1,750	2,113	1.21	18	.5	51	16	12	.0	154	74	6.3	2.8	275
June 11	June 20	1,400	2,033	1.45	26	.8	.....	17	10	.0	.....	67	9.5	2.5	303
June 21	June 30	1,200	1,328	1.11	21	.16	60	19	12	.0	218	62	2.8	2.1	299
July 1	July 10	1,300	2,035	1.56	24	.6	55	20	15	.0	214	69	3.3	4.6	296
July 11	July 20	1,670	1,939	1.16	33	.8	.....	...	13	.0	155	44	6.2	2.5	231
July 21	July 30	1,100	1,268	1.15	17	.16	42	14	8.4	.0	185	35	1.9	1.2	212
July 31	Aug. 9	830	910	1.10	33	.12	62	21	7.1	.0	249	52	5.0	1.8	310
Aug. 11	Aug. 20	2,400	2,591	1.08	31	.6	47	13	19	.0	175	51	7.1	2.8	259
Aug. 21	Aug. 30	550	456	.83	9.2	.04	64	22	23	.0	243	71	2.0	5.0	327
Aug. 31	Sept. 9	500	844	1.69	.....	.18	49	16	20	.0	165	....	2.2	3.4	251
Mean		542	642	1.09	22	.36	58	21	17	.0	216	71	3.3	4.8	312
Per ct. of anhydrous residue		.....	.....	.....	7.2	[b].2	19.0	6.9	5.6	35.0	....	23.4	1.1	1.6	....

[a] Analyses September 10, 1906, to February 19, 1907, by W. M. Barr; February 20 to March 1, 1907, by H. S. Spaulding; March 2 to September 9, 1907, by Walton Van Winkle.

[b] Fe_2O_3.

Mineral analyses of water from Lake Erie at Buffalo, N. Y.[a]

[Parts per million, unless otherwise stated.]

Date (1906–7).	Turbidity.	Suspended matter.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg.)	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.	Mean gage height (feet).
Sept. 19	2	....	11	0.13	33	7.1	7.2	4.1	118	12	0.40	8.0	143	572.27
Oct. 19	2	....	11	.08	32	6.8	6.3	4.8	116	11	.00	7.9	138	572.25
Nov. 19	17	....	4.2	.04	31	7.4	5.8	.0	124	12	Tr.	8.2	129	572.32
Dec. 19	24	....	7.6	.04	31	7.4	6.8	3.6	118	13	Tr.	8.6	136	572.45
Jan. 19	190	....	2.9	.07	30	7.4	6.4	.0	117	13	.25	9.2	126	572.96
Mar. 19	13	....	4.5	.10	31	7.5	5.8	2.2	112	14	.25	9.2	132	572.22
Apr. 19	.....	.....	8.6	.06	30	8.2	6.9	1.4	108	13	.35	8.4	129	572.62
May 25	.....	.....	4.7	.05	31	7.9	6.5	4.0	104	14	.6	8.6	132	572.84
June 19	.....	.....	4.6	.03	31	7.9	6.7	5.3	110	13	.45	8.8	131	573.18
July 19	.....	.....	3.9	.03	32	7.8	7.1	5.2	110	14	.50	9.2	134	573.33
Aug. 28	.....	.....	2.1	.18	31	8.0	5.9	3.4	112	13	.35	8.6	128	573.02
Mean	41	Tr.	5.9	.07	31	7.6	6.5	3.1	114	13	.3	8.7	133	.....
Per ct. of anhydrous residue	.....	.....	4.5	[b].1	23.4	5.7	4.9	44.8	.....	9.8	.2	6.6	.....	.....

[a] Analyses by R. B. Dole and M. G. Roberts.
[b] Fe_2O_3.

Mineral analyses of water from Flint River near Albany, Ga.[a]

[Parts per million, unless otherwise stated.]

Date (1906–7).		Turbidity.	Suspended matter.	Coefficient of fineness.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).[b]	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).[c]	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.	Mean gage height (feet).
From—	To—															
Oct. 23	Nov. 1	120	64	0.53	47	.....	6.8	3.6	.....	0.0	29	.....	1.8	3.0	84	4.3
Nov. 2	Nov. 11	45	31	.69	19	0.8	11	4.8	.....	.0	51	.....	.4	3.0	80	1.8
Nov. 12	Nov. 21	17	4	.24	25	.20	11	Tr.	.....	.0	32	.....	.9	2.5	74	2.3
Nov. 22	Dec. 1	20	8	.40	27	.30	12	1.2	.....	.0	34	.....	.6	2.0	77	3.0
Dec. 2	Dec. 11	25	11	.44	33	.20	12	1.2	.....	.0	37	.....	.7	2.2	90	1.9
Dec. 12	Dec. 21	35	18	.51	34	.5	14	1.6	.....	.0	49	.....	.5	2.5	93	2.1
Dec. 22	Dec. 31	40	17	.42	20	.9	6.0	.8	.....	.0	29	.....	.8	3.0	68	3.8
Jan. 1	Jan. 11	35	20	.07	18	.8	6.2	1.2	.....	.0	22	.....	.5	3.0	62	5.4
Jan. 12	Jan. 22	20	15	.75	22	.10	8.1	.8	.....	.0	34	.....	.8	4.0	63	2.8
Jan. 23	Feb. 2	12	7	.58	16	.8	7.0	.8	.....	.0	24	.....	1.1	5.5	52	3.0
Feb. 2	Feb. 11	120	89	.74	36	.9	5.6	.8	.....	.0	22	.....	.4	2.0	66	7.9
Feb. 12	Feb. 21	60	53	.88	22	1.1	6.8	.8	.....	.0	22	.....	.7	4.0	70	5.8
Feb. 22	Mar. 3	65	45	.69	14	1.2	8.4	1.2	.....	.0	27	.....	.1	2.5	47	3.8
Mar. 4	Mar. 13	85	64	.75	18	1.4	8.8	1.2	.....	.0	29	.....	.4	3.0	54	5.8
Mar. 14	Mar. 23	40	36	.90	12	.7	6.4	.8	.....	.0	22	.....	.3	1.5	39	4.1
Mar. 24	Apr. 2	30	30	1.00	24	1.4	10	1.2	.....	.0	37	.....	.7	3.0	72	2.1
Apr. 3	Apr. 12	60	50	.83	19	.8	10	.8	.....	.0	34	.....	.3	2.5	59	3.8
Apr. 13	Apr. 22	160	156	.98	23	.9	9.5	2.5	.....	.0	34	.....	.3	2.0	60	3.6
Apr. 23	May 2	460	376	.82	27	1.3	9.0	1.6	.....	.0	34	.....	.2	3.5	66	9.4
May 3	May 12	560	.....	.....	33	2.1	7.0	1.2	.....	.0	24	.....	.1	2.0	60	7.2
Mean		100	58	.67	24	.86	8.8	1.4	[b]7.0	.0	31	[c]6.0	.6	2.8	67	....
Per ct. of anhydrous residue[d]		.....	.....	.....	35.8	[e]1.8	13.0	2.1	10.4	22.8	.....	9.0	.9	4.2	....	....

[a] Analyses by J. R. Evans.
[b] Fluctuates between 2 and 10 parts. Average value about 7 parts.
[c] Fluctuates between trace and 8 parts. Average value about 6 parts.
[d] Approximate.
[e] Fe_2O_3.

Mineral analyses of water from Grand River at Grand Rapids, Mich.[a]

[Parts per million, unless otherwise stated.]

Date (1906–7). From—	To—	Turbidity.	Suspended matter.	Coefficient of fineness.	Total iron (Fe).	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.	Mean gage height (feet).
Oct. 1	Oct. 10	10	39	3.90	0.3	10	Tr.	55	19	10	7.2	220	29	0.7	9.6	256	0.1
Oct. 11	Oct. 20	8	10	1.25	Tr.	19	Tr.	59	20	13	11	244	23	1.0	7.9	277	— .2
Oct. 21	Oct. 30	7	9	1.29	Tr.	22	Tr.	60	21	13	Tr.	269	24	.7	6.7	277	.1
Oct. 31	Nov. 9	4	5.2	1.30	....	16	0.04	62	21	11	4.8	254	29	1.5	7.9	282	.4
Nov. 10	Nov. 19	3	2.8	.93	....	16	.03	65	22	9.0	13	244	31	1.5	8.2	290	.1
Nov. 20	Nov. 29	19	22	1.16	.05	17	.03	63	21	7.4	9.1	234	37	3.0	7.9	286	2.1
Dec. 1	Dec. 11	5	4.0	.80	.16	21	.03	67	20	8.7	.0	246	47	5.0	6.7	303	1.6
Dec. 12	Dec. 29	7	7.0	1.00	.2	15	.03	69	22	6.6	.0	246	49	7.0	8.8	311	1.8
Jan. 2	Jan. 10	375	255	.68	4.9	11	.12	52	16	7.9	.0	198	39	6.0	6.2	240	4.5
Jan. 11	Jan. 23	....	46	.....	2.1	13	.3	45	13	7.4	4.3	148	34	6.0	6.7	210	6.6
Jan. 24	Feb. 6	21	34	1.62	1.3	21	.07	45	14	6.3	4.1	158	32	3.1	4.0	198	10.4
Feb. 7	Feb. 17	28	65	2.32	.5	5.6	.04	41	21	11	14	172	42	.....	6.5	219	6.8
Feb. 18	Feb. 27	9	19	2.11	.4	24	.07	64	19	8.7	17	198	42	4.0	5.8	283	5.4
Feb. 28	Mar. 9	38	76	2.00	1.1	2.8	.05	41	15	8.2	.....	.....	36	1.7	4.8	201	5.0
Mar. 10	Mar. 19	42	65	1.55	1.8	6.6	.09	42	13	7.9	18	145	30	1.5	4.3	195	6.0
Mar. 20	Mar. 29	55	86	1.57	2.6	6.0	.12	42	12	6.0	8.4	146	26	2.0	4.1	191	7.1
Mar. 30	Apr. 8	34	36	1.06	1.1	11	.08	47	14	9.1	11	162	30	4.0	7.8	219	6.3
Apr. 9	Apr. 19	7	18	2.57	.5	15	.04	58	18	13	15	202	35	3.5	7.2	269	2.8
Apr. 20	May 1	36	35	.97	1.2	15	.10	60	18	11	16	207	35	2.5	7.8	272	2.0
May 2	May 12	36	40	1.11	1.4	16	.12	50	15	11	12	179	30	2.0	6.0	235	5.7
May 13	May 24	9	13	1.44	.4	26	.08	60	19	9.7	7.2	232	35	4.0	9.0	292	1.6
May 25	June 4	26	23	.88	.5	9.6	.10	61	19	13	12	231	33	3.0	9.6	280	1.7
June 5	June 14	5	15	3.00	.6	8.2	.05	61	19	15	7.2	235	35	2.0	7.8	279	1.0
June 15	June 24	20	45	2.25	.8	8.0	.14	60	20	14	7.2	238	30	1.0	7.4	269	.4
June 25	July 4	9	20	2.22	.4	13	.06	60	20	10	.0	257	28	1.7	10	273	.5
July 5	July 15	15	30	2.00	1.0	15	.05	61	22	13	.....	.....	31	Tr.	9.8	270	.2
July 16	July 25	200	172	.86	4.4	21	.09	59	20	12	14	204	30	1.6	9.4	265	1.2
July 26	Aug. 6	40	56	1.40	1.6	10	.06	59	20	9.8	7.2	229	32	.2	9.4	259	.6
Aug. 7	Aug. 16	20	41	2.05	.8	15	.05	60	22	10	11	226	32	.8	8.6	266	.3
Aug. 17	Aug. 26	15	31	2.07	1.1	12	.05	58	23	8.8	12	217	31	1.4	9.4	263	.3
Aug. 27	Sept. 5	20	36	1.80	1.0	24	.05	59	22	15	.0	249	35	1.2	12	286	.3
Sept. 6	Sept. 15	15	22	1.47	1.2	14	.04	58	22	9.1	7.2	228	30	1.5	9.0	263	.2
Sept. 16	Sept. 25	70	84	1.20	2.6	2.4	.06	53	18	9.3	13	182	30	Tr.	8.2	232	.3
Sept. 26	Oct. 5	12	15	1.25	.5	20	.04	59	21	15	9.6	237	29	2.0	8.6	277	.6
Mean		37	43	1.61	1.1	14	.07	56	19	10	8.5	214	33	2.3	7.7	258	.....
Per ct. of anhydrous residue		.....	.....	.....	....	5.5	[b]0	21.9	7.4	3.9	44.5	.....	12.9	.9	3.0	.....	.....

[a] Analyses October 1, 1906, to November 29, 1906, by R. B. Dole; January 2 to March 29, 1907, by R. B. Dole and M. G. Roberts; March 30 to July 4, 1907, by Chase Palmer and M. G. Roberts; July 5 to October 5, 1907, by R. B. Dole, Chase Palmer, and W. D. Collins.

[b] Fe_2O_3.

Mineral analyses of water from Hudson River at Hudson, N. Y.[a]

[Parts per million, unless otherwise stated.]

Date (1906-7).		Turbidity.	Suspended matter.	Coefficient of fineness.	Total iron (Fe).	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.
From—	To—															
Sept. 17	Sept. 27	10	11	1.10	0.6	19	0.2	24	4.4	7.9	0.0	87	16	Tr.	3.8	131
Sept. 28	Oct. 7	9	9	1.00	.4	15	.2	24	4.2	7.9	.0	80	17	0.5	5.3	129
Oct. 8	Oct. 17	6	7	1.17	.2	9.0	.1	26	3.8	10	.0	80	20	.9	5.6	131
Oct. 18	Oct. 28	7	11	1.57	.3	13	.05	26	3.8	11	.0	82	20	.7	5.3	135
Oct. 29	Nov. 7	8	11	1.37	.....	13	.18	25	4.8	9.9	.0	79	21	.9	4.1	125
Nov. 8	Nov. 17	8	10	1.25	.....	15	.16	22	4.4	10	.0	77	21	.9	4.1	123
Nov. 18	Nov. 27	18	13	.72	.8	13	.2	20	4.2	7.9	.0	71	15	1.0	3.0	112
Nov. 28	Dec. 8	9	10	1.11	.3	8.6	.15	18	3.8	6.3	.0	63	12	.5	2.6	96
Dec. 9	Dec. 18	8	6.6	.75	.6	8.0	.08	20	4.2	7.3	.0	72	16	1.6	4.3	99
Dec. 19	Dec. 28	8	6.8	.85	.5	11	.06	24	5.0	7.6	.0	83	18	1.5	4.4	114
Dec. 29	Jan. 8	39	40	1.02	1.4	7.4	.1	18	4.0	6.3	.0	60	14	1.8	2.9	88
Jan. 9	Jan. 18	31	30	.97	1.1	12	.16	15	3.4	4.6	.0	52	12	1.2	3.4	82
Jan. 19	Jan. 27	13	21	1.62	.6	5.6	.09	18	4.0	5.0	.0	57	15	1.1	3.6	86
Jan. 31	Feb. 9	6	6.4	1.07	.4	9.6	.12	21	4.6	5.0	.0	67	16	1.6	4.1	103
Feb. 10	Feb. 20	18	32	1.78	.4	4.2	.1	19	4.8	6.6	.0	70	17	.0	4.3	99
Feb. 21	Mar. 2	9	11	1.22	.8	9.6	.13	24	5.0	5.7	.0	77	19	2.0	5.0	118
Mar. 3	Mar. 12	6	2.6	.43	.4	27	.13	25	4.8	5.8	.0	76	21	2.1	5.0	129
Mar. 13	Mar. 22	20	21	1.05	1.1	13	.13	20	4.0	4.9	.0	63	16	2.1	4.2	98
Mar. 23	Apr. 1	34	54	1.59	2.1	5.6	.13	16	2.2	5.0	[b]7.9	43	9.7	.3	1.2	63
Apr. 2	Apr. 12	15	16	1.07	.5	15	.09	16	1.2	9.8	.0	61	13	1.3	2.9	94
Apr. 13	Apr. 22	13	19	1.46	.7	9.2	.12	16	1.4	6.9	.0	56	10	1.0	3.0	82
Apr. 23	May 2	30	33	1.10	1.4	13	.16	16	1.4	9.4	.0	56	12	.9	2.4	87
May 3	May 12	12	15	1.25	.6	12	.13	.....	1.0	5.0	.0	48	12	.8	2.4	77
May 13	May 22	7	9.0	1.29	.5	9.0	.15	16	1.2	7.6	.0	62	11	.8	2.4	84
May 23	June 1	6	11	1.83	.5	10	.15	18	1.4	6.3	.0	.....	13	.6	3.4	96
June 2	June 11	7	10	1.43	.5	5.4	.11	18	1.8	.....	.0	63	.....	.5	3.4	92
June 12	June 21	6	9.6	1.60	.4	4.8	.11	20	2.0	6.9	.0	.....	14	.5	3.4	93
June 22	July 1	29	34	1.17	1.0	6.6	.09	22	4.0	9.5	[b]12	56	14	Tr.	6.2	103
July 2	July 11	20	30	1.50	.8	9.2	.12	.....	5.4	9.8	[b]12	60	19	.0	5.8	117
July 12	July 21	4	11	2.75	.8	16	.40	22	4.6	11	.0	83	17	Tr.	3.8	122
July 22	July 31	9	13	1.44	.8	11	.11	26	4.6	12	.0	92	20	Tr.	3.4	127
Aug. 1	Aug. 10	7	2.2	.31	.7	10	.21	26	5.0	9.4	.0	88	20	Tr.	5.0	127
Aug. 11	Aug. 21	8	23	2.88	.8	.....	.14	26	5.4	9.3	[b]4.8	84	19	.0	5.4	125
Aug. 22	Sept. 1	7	6.6	.94	.7	8.0	.23	26	5.4	9.8	.0	95	21	.0	5.4	131
Sept. 2	Sept. 11	9	6.8	.76	.9	8.8	.42	26	5.8	8.8	.0	87	22	Tr.	5.8	133
Sept. 12	Sept. 22	11	12	1.09	.7	13	.10	26	5.4	9.4	.0	85	23	Tr.	4.2	132
Mean		13	16	1.26	.7	11	.15	21	3.8	7.9	.0	73	16	.8	4.0	108
Per ct. of anhydrous residue		....	.....	.....	.....	10.9	c.2	20.9	3.8	7.8	35.7	.....	15.9	.8	4.0	....

[a] Analyses September 17 to December 8, 1906, by R. B. Dole; December 9, 1906, to April 1, 1907, by R. B. Dole and M. G. Roberts; April 2 to July 1, 1907, by Chase Palmer and M. G. Roberts; July 2 to September 22, 1907, by R. B. Dole, Chase Palmer, and W. D. Collins.

[b] Abnormal; computed as HCO_3 in the average.

[c] Fe_2O_3.

Mineral analyses of water from Lake Huron at Port Huron, Mich.[a]

[Parts per million, unless otherwise stated.]

Date (1906-7).	Turbidity.	Suspended matter.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.	Mean gage height (feet).[b]
Sept. 21	1	....	13	0.02	24	6.4	3.5	3.4	97	4.8	0.30	2.5	108	581.12
Oct. 21	2	....	8.7	.10	24	6.3	3.7	3.6	96	6.2	.25	2.5	105	580.87
Nov. 21	Tr.	....	8.0	.05	24	6.7	3.0	.0	100	5.6	.4	2.6	101	580.68
Dec. 21	Tr.	....	12	.05	23	6.7	3.5	.0	103	6.6	.3	3.1	106	580.65
Jan. 21	.....	.....	12	.03	23	7.1	5.8	.0	99	6.7	.4	2.5	108	580.65
Mar. 21	.....	.....	14	.03	22	7.2	4.7	1.2	101	6.7	.3	2.5	109	580.68
Apr. 21	.....	.....	14	.04	24	7.7	5.1	Tr.	106	6.0	.45	2.6	110	580.90
May 21	.....	.....	14	.05	25	7.6	5.9	2.4	102	7.3	.4	2.8	116	581.08
June 21	.....	.....	8.5	.04	24	7.5	4.7	5.3	96	6.4	.45	2.8	105	581.39
Mean	Tr.	Tr.	12	.04	24	7.0	4.4	1.8	100	6.2	.4	2.6	108	.....
Per ct. of anhydrous residue	.....	.....	11.1	c.0	22.3	6.5	4.1	47.4	.....	5.8	.4	2.4	.....	.....

[a] Analyses by R. B. Dole and M. G. Roberts.
[b] Gaging station at Harbor Beach, Mich., 60 miles above.
[c] Fe_2O_3.

Mineral analyses of water from Iowa River at Iowa City, Iowa.[a]

[Parts per million, unless otherwise stated.]

Date (1906–7).		Turbidity.	Suspended matter.	Coefficient of fineness.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.
From—	To—														
Sept. 6	Sept. 15	90	64	0.71	28	.....	57	20	17	[b]7.7	245	31	0.2	3.8	253
Sept. 16	Sept. 25	105	74	.70	28	0.30	47	18	19	.0	222	.....	1.8	5.0	264
Sept. 26	Oct. 6	125	86	.69	24	.10	51	21	13	.0	223	36	1.7	6.7	265
Oct. 7	Oct. 16	75	62	.83	22	.10	56	23	14	.0	273	32	1.1	4.0	273
Oct. 17	Oct. 26	50	51	1.02	36	Tr.	64	26	13	.0	283	44	.5	3.9	312
Oct. 27	Nov. 5	25	22	.88	21	Tr.	63	22	12	.0	262	35	1.3	5.4	289
Nov. 6	Nov. 15	20	13	.65	14	Tr.	60	20	16	.0	268	30	1.5	4.4	291
Nov. 16	Nov. 25	15	14	.93	10	.10	59	21	17	.0	275	36	Tr.	3.7	276
Nov. 26	Dec. 5	35	29	.83	15	.15	53	20	16	.0	253	36	4.4	4.5	270
Dec. 6	Dec. 16	20	13	.65	26	.10	61	18	16	.0	282	42	4.4	4.0	312
Dec. 17	Jan. 4	70	41	.59	27	.05	61	24	.....	.0	281	31	3.5	4.0	306
Jan. 5	Jan. 15	135	102	.76	14	.6	23	10	11	.0	90	31	5.2	2.1	139
Jan. 16	Jan. 28	115	87	.76	18	.7	21	7.5	.....	.0	83	30	1.7	2.7	134
Jan. 29	Feb. 7	10	7.2	.72	.12	.15	39	15	14	.0	160	39	2.3	3.4	196
Feb. 8	Feb. 17	15	26	1.73	8.8	.07	44	13	12	.0	165	44	2.2	6.7	211
Feb. 18	Feb. 27	75	69	.92	6.2	.15	.....	9.2	12	.0	79	34	6.9	1.4	129
Feb. 28	Mar. 9	240	213	.89	9.2	.9	.....	11	14	.0	118	51	6.4	1.8	187
Mar. 10	Mar. 19	170	109	.64	18	.05	35	11	18	.0	141	36	4.0	2.0	192
Mar. 20	Mar. 29	90	62	.69	.....	.16	46	15	12	.0	195	38	1.3	3.3	231
Mar. 30	Apr. 8	285	140	.49	15	.45	44	16	9.5	.0	208	36	4.1	.....	221
Apr. 9	Apr. 18	50	30	.60	14	.10	59	21	12	.0	228	49	1.0	3.2	285
Apr. 19	Apr. 28	30	37	1.24	13	.03	61	23	15	.0	270	49	Tr.	4.2	319
Apr. 30	May 8	50	55	1.10	13	.40	46	18	15	.0	.....	47	.6	5.4	284
May 9	May 18	50	.....	.....	9.8	.15	57	24	12	.0	270	38	Tr.	3.3	284
May 19	May 28	540	377	.70	36	1.4	48	14	11	.0	202	36	5.4	2.4	278
May 29	June 7	190	124	.65	17	.10	47	16	9.1	.0	181	37	2.9	3.2	232
June 8	June 16	650	476	.73	23	.40	38	13	11	.0	161	30	3.5	1.9	217
June 17	June 26	255	187	.68	25	.30	47	17	26	.0	.....	32	3.4	4.3	270
June 27	July 7	350	214	.61	26	.30	55	20	11	.0	252	33	4.4	2.6	268
July 8	July 17	1,200	757	.63	25	.35	30	8.2	.....	.0	114	40	3.0	.....	172
July 18	July 27	375	257	.67	22	.7	35	9.6	9.9	.0	153	22	7.2	.....	192
July 28	Aug. 7	162	117	.72	22	.06	55	16	15	.0	238	29	3.1	1.6	266
Aug. 8	Aug. 17	175	118	.67	20	.10	48	17	11	.0	218	32	3.9	2.4	249
Aug. 18	Aug. 27	75	50	.67	24	.19	59	18	8.9	.0	245	34	3.0	2.8	288
Aug. 28	Sept. 6	80	71	.89	16	.11	52	19	.....	.0	222	33	3.0	4.2	243
Sept. 7	Sept. 16	50	63	1.26	17	.02	57	20	18	.0	267	38	.6	3.8	285
Mean		168	120	.80	19	.25	49	17	14	.0	210	36	2.8	3.6	247
Per ct. of anhydrous residue		.....	.....	.....	7.8	c.1	20.0	6.9	5.7	42.2	.....	14.7	1.1	1.5	....

[a] Analyses September 6, 1906, to February 17, 1907, by W. M. Barr; February 18 to 27, 1907, by Henry S. Spaulding; February 28 to September 16, 1907, by Walton Van Winkle.

[b] Abnormal; computed as HCO_3 in the average.

[c] Fe_2O_3.

Mineral analyses of water from James River at Richmond, Va.[a]

[Parts per million, unless otherwise stated.]

Date (1906–7). From—	To—	Turbidity.	Suspended matter.	Coefficient of fineness.	Total iron (Fe).	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.	Mean gage height (feet).
Sept. 10	Sept. 19	38	29	0.76	2.5	25	0.6	17	4.0	6.8	0.0	72	4.3	Tr.	2.4	100	0.7
Sept. 20	Sept. 29	43	15	.35	2.8	30	1.0	17	4.2	6.3	.0	76	5.1	0.4	2.2	119	.6
Sept. 30	Oct. 8	400	85	.21	21	54	1.3	17	3.2	4.7	.0	69	12	.4	Tr.	146	2.8
Oct. 10	Oct. 19	70	32	.46	3.5	15	.5	15	2.6	5.8	.0	58	5.1	.9	1.9	83	1.1
Oct. 20	Oct. 29	270	56	.21	7.1	21	.8	12	2.0	6.7	.0		3.9	.9	1.4	93	7.2
Oct. 30	Nov. 8	14	18	1.29	1.1	31	.3	15	3.6	6.9	.0	68	5.6	.7	2.9	98	1.0
Nov. 9	Nov. 18	12	12	1.00	0.5	25	.2	16	4.0	6.6	.0	71	10	.5	2.2	97	.6
Nov. 19	Nov. 28	260	227	.87	8.6	14	.9	11	1.4	4.6	.0	46	5 8	.4	1.4	71	2.1
Nov. 29	Dec. 8	14	11	.79	0.8	18	.3	13	2.4	3.9	.0	58	4.6	.2	.2	76	.7
Dec. 9	Dec. 18	11	7.4	.67	0.9	17	.25	14	4.2	3.0	.0	60	5.1	.1	2.2	79	.6
Dec. 19	Dec. 29	47	53	1.12	3.0	11	.4	13	3.0	1.8	.0	54	5.9	.2	2.2	71	1.3
Dec. 30	Jan. 8	55	59	1.07	5.8	16	.8	11	2.8	....	.0	46	4.9	.7	1.9	71	1.5
Jan. 9	Jan. 19	9	20	2.23	1.3	15	.23	13	3.2	....	.0	56	4.6	.4	1.9	73	1.1
Jan. 20	Jan. 29	21	44	2.10	2.3	12	.26	12	2.8	....	.0	50	4.3	.5	1.8	63	1.2
Jan. 30	Feb. 8	6	10	1.67	0.8	14	.35	13	3.2	....	.0	53	5.1	Tr.	2.4	70	1.0
Feb. 9	Feb. 18	24	18	.75	1.2	11	.6	13	3.4	3.6	.0	55	5.1	Tr.	3.0	69	1.0
Feb. 19	Mar. 1	17	15	.88	0.6	13	.18	13	2.0	4.7	.0	51	8.8	.9	1.7	70	1.0
Mar. 3	Mar. 12	55	47	.85	1.8	17	.67	12	2.3	6.1	.0	49	7.7	.7	1.0	76	1.4
Mar. 12	Mar. 22	55	50	.91	1.8	13	.23	12	2.5	6.1	.0	51	5.8	.6	1.0	69	1.8
Mar. 23	Apr. 2	38	25	.66	1.9	16	.19	14	2.5	6.8	.0	59	12	.3	1.4	83	.9
Apr. 3	Apr. 12	190	194	1.02	8.6	24	.7	13	1.8	11	.0	60	8.4	.0	2.6	97	3.5
Apr. 13	Apr. 22	42	64	1.52	2.1	26	.16	13	1.6	10	.0	59	5.6	.0	1.8	91	1.6
Apr. 23	May 3	80	70	.87	2.7	....	.7	16	3.2	14	[b] 17	55	7.4	Tr.	3.4	174	1.3
May 4	May 13	220	190	.86	10	22	1.8	11	1.4	6.6	.0	52	6.6	.0	2.2	88	1.8
May 14	May 23	70	64	.91	2.6	24	.35	12	1.8	9.4	[b] 2.4	54	6.9	Tr.	1.8	91	1.2
May 24	June 2	110	125	1.14	5.6	20	.3	13	1.9	8.8	.0	62	7.2	Tr.	2.2	88	1.5
June 3	June 12	230	256	1.13	14	6.4	.5	9.6	0.6	6.9	[b] 2.4	33	7.7	.0	2.4	58	3.8
June 13	June 22	235	240	1.02	11	11	.3	12	0.4	7.2	[b] 11	27	6.1	.0	2.2	69	3.6
June 23	July 2	110	126	1.14	5.4	19	.24	15	0.6	9.8	[b] 12	46	6.2	Tr.	2.4	93	1.2
July 3	July 12	48	40	.83	1.2	11	.04	16	4.0	8.0	.0	62	7.6	.3	3.8	82	.6
July 13	July 22	20	29	1.45	0.6	17	.06	18	4.6	5.7	.0	71	8.4	.2	3.6	94	.6
July 23	Aug. 1	100	81	.81	1.4	14	.28	18	4.8	6.1	.0	67	11	Tr.	4.6	97	.4
Aug. 2	Aug. 11	45	36	.80	1.0	16	.05	18	4.8	7.2	.0	71	9.9	.4	3.6	98	.2
Aug. 12	Aug. 21	120	75	.62	1.6	18	1.5	17	5.2	6.9	.0	....	10	.7	3.6	100	.5
Aug. 22	Sept. 1	28	33	1.18	1.2	12	.19	19	5.5	5.0	[b] 3.6	67	10	.3	3.6	97	.3
Sept. 2	Sept. 9	150	90	.60	1.5	16	.79	19	5.1	6.0	.0	....	11	Tr.	3.2	100	.2
Mean		90	71	.96	3.9	18	.5	14	3.0	6.7	.0	60	7.1	.3	2.3	89	....
Per ct. of anhydrous residue		....	....	....	....	22.0	[c] 9	17.1	3.7	8.2	36.2	....	8.7	.4	2.8	....	....

[a] Analyses September 10 to November 28, 1906, by R. B. Dole; November 29, 1906, to April 2, 1907, by R. B. Dole and M. G. Roberts; April 3 to July 2, 1907, by Chase Palmer and M. G. Roberts; July 12 to September 9, 1907, by R. B. Dole, Chase Palmer, and W. D. Collins.

[b] Abnormal; computed as HCO_3 in the average.

[c] Fe_2O_3.

Mineral analyses of water from Kalamazoo River near Kalamazoo, Mich.[a]

[Parts per million, unless otherwise stated.]

Date (1906–7).		Turbidity.	Suspended matter.	Coefficient of fineness.	Total iron (Fe).	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.
From—	To—															
Sept. 19	Sept. 28	3	.....	.....	0.3	29	0.3	59	20	9.0	6.8	250	16	1.5	3.8	272
Sept. 29	Oct. 8	4	.....	.....	.3	19	.3	58	20	8.7	9.8	236	22	1.5	3.8	265
Oct. 9	Oct. 18	5	12	2.40	Tr.	20	Tr.	62	19	8.8	8.4	257	15	2.1	4.3	261
Oct. 19	Oct. 28	3	7.0	2.33	Tr.	20	Tr.	62	19	8.5	5.8	264	14	1.6	3.6	262
Oct. 29	Nov. 7	5	7.6	1.52	.1	16	Tr.	64	18	6.1	17	238	28	2.6	3.8	278
Nov. 8	Nov. 17	9	7.2	.80	Tr.	17	Tr.	63	18	6.5	.0	271	25	2.4	3.8	284
Nov. 18	Nov. 27	8	7.4	.92	.1	19	Tr.	66	19	8.3	.0	250	27	2.8	3.6	262
Nov. 27	Dec. 7	4	4.8	1.20	Tr.	21	Tr.	64	19	7.2	Tr.	253	21	2.8	3.4	267
Dec. 8	Dec. 18	7	3.2	.46	.1	15	.06	60	18	5.4	5.3	222	31	0.8	3.0	255
Dec. 19	Dec. 28	5	3.2	.64	.1	20	.07	68	21	5.8	17	234	31	3.2	3.6	289
Dec. 29	Jan. 1	6	5.6	.93	.3	17	.07	63	19	4.9	.0	252	24	3.2	3.4	262
Jan. 8	Jan. 17	11	13	1.18	.8	22	06	56	17	3.3	.0	213	31	3.2	3.4	241
Jan. 18	Jan. 28	11	11	1.00	.6	11	.03	52	16	5.5	.0	198	28	3.2	3.0	223
Jan. 29	Feb. 8	9	54	6.00	.4	11	.05	49	19	7.1	19	202	32	1.9	3.5	228
Feb. 9	Feb. 18	19	89	4.68	.3	2.8	.06	31	19	8.4	14	160	25	.2	2.9	174
Feb. 19	Feb. 28	13	85	6.54	.2	3.4	.06	22	17	7.4	19	121	...	.0	3.1	140
Mar. 11	Mar. 20	4	7.0	1.75	.4	23	.06	57	17	6.9	14	220	23	3.6	3.0	252
Mar. 21	Mar. 27	9	15	1.67	.8	15	.05	52	14	6.3	4.8	193	22	2.0	2.4	223
Mar. 31	Apr. 9	9	16	1.78	.3	19	.06	52	14	11	14	173	26	2.0	3.6	235
Apr. 10	Apr. 21	10	25	2.50	.15	26	.06	..	16	....	17	160	24	3.5	4.6	232
Apr. 22	May 1	8	12	1.50	.3	24	.05	59	17	10	17	218	20	2.5	3.6	265
May 2	May 11	13	19	1.46	1.6	8.8	.05	49	15	6.9	12	163	30	2.5	3.4	214
May 12	May 21	2	3.5	1.75	.1	19	.07	60	18	12	12	234	22	1.8	3.4	263
May 22	June 1	4	6.5	1.62	.2	14	.06	58	18	10	12	235	20	1.5	2.8	252
June 2	June 11	6	9.5	1.58	.2	12	.03	58	18	11	11	228	20	2.5	3.0	249
June 12	June 22	3	6.5	2.17	.3	15	.05	58	19	13	Tr.	249	19	1.6	3.4	254
June 23	July 3	3	32	10.65	.6	16	.06	56	20	9.5	4.8	227	17	Tr.	4.2	241
July 4	July 13	10	95	9.50	Tr.	22	Tr.	37	20	.....	.0	174	22	Tr.	2.6	189
July 14	July 23	7	36	5.14	Tr.	11	Tr.	37	19	.....	9.6	135	20	Tr.	2.4	186
July 24	Aug. 2	4	11	2.75	Tr.	23	Tr.	58	20	.....	12	202	20	.9	2.2	256
Aug. 3	Aug. 12	3	7.0	2.33	Tr.	14	Tr.	55	19	10	Tr.	228	20	1.5	4.5	233
Aug. 13	Aug. 22	3	8.4	2.80	Tr.	19	Tr.	38	21	....	.0	167	19	2.0	3.6	196
Aug. 23	Sept. 1	2	5.0	2.50	Tr.	23	Tr.	58	21	12	.0	251	21	1.5	3.4	254
Sept. 2	Sept. 11	3	5.4	1.80	Tr.	22	Tr.	58	21	.....	.0	246	20	1.4	3.6	257
Sept. 12	Sept. 21	6	7.6	1.27	Tr.	18	Tr.	57	20	11	9.6	226	19	1.3	3.8	245
Mean		7	19	2.64	.2	17	.05	55	18	8.2	7.8	216	23	1.9	3.4	242
Per ct. of anhydrous residue		....	.....	.....	.....	7.1	[b].0	22.9	7.5	3.4	47.3	.....	9.6	0.8	1.4	....

[a] Analyses September 19 to December 7, 1906, by R. B. Dole; December 8, 1906, to March 27, 1907, by R. B. Dole and M. G. Roberts; March 31 to July 3, 1907, by Chase Palmer and M. G. Roberts; July 13 to September 21, 1907, by R. B. Dole, Chase Palmer, and W. D. Collins.

[b] Fe_2O_3.

Mineral analyses of water from Kentucky River at Frankfort, Ky.[a]

[Parts per million, unless otherwise stated.]

Date (1906-7).		Turbidity.	Suspended matter.	Coefficient of fineness.	Total iron (Fe).	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.	Mean gage height (feet).
From—	To—																
Aug. 28	Sept. 7	70	63	0.90	2.7	15	0.9	.....	2.2	11	0.0	77	5.4	Tr.	1.4	102	6.4
Sept. 8	Sept. 17	180	108	.60	4.0	28	1.2	18	4.2	8.9	.0	80	6.4	1.5	1.7	120	6.8
Sept. 18	Sept. 27	165	84	.51	5.2	23	1.4	21	2.6	7.2	.0	76	7.6	2.4	1.9	117	6.4
Sept. 28	Oct. 7	160	101	.63	4.9	21	.8	30	4.6	9.1	.0	111	8.2	2.6	1.7	147	7.3
Oct. 8	Oct. 18	105	73	.69	2.7	19	.6	27	4.8	6.5	.0	103	8.7	2.8	2.4	133	7.0
Oct. 19	Oct. 28	50	34	.68	2.0	5.2	.4	21	4.2	5.5	.0	83	7.6	1.7	2.2	105	6.0
Oct. 29	Nov. 8	43	25	.58	..	19	.3	22	4.6	6.8	.0	89	8.9	2.0	2.4	111	5.8
Nov. 9	Nov. 19	32	19	.59	...	14	.12	25	4.4	7.2	.0	90	7.9	2.1	2.2	112	5.8
Nov. 20	Nov. 30	...	406	....	8.8	12	.7	26	4.0	6.5	.0	89	10	5.0	3.0	117	8.9
Dec. 1	Dec. 12	105	41	.39	1.9	15	.6	26	5.4	4.3	.0	80	...	6.2	...	117	6.2
Dec. 13	Dec. 23	450	430	.96	9.3	15	.65	27	4.8	3.6	.0	99	6.9	7.4	1.8	125	10.6
Dec. 24	Jan. 2	270	206	.76	5.8	18	1.4	25	4.6	3.0	.0	79	7.9	6.4	1.7	118	10.2
Jan. 3	Jan. 12	210	140	.67	3.2	14	.4	28	4.8	3.6	.0	94	9.4	7.4	1.4	121	9.5
Jan. 13	Jan. 22	700	660	.94	16	15	.7	26	5.2	5.2	.0	96	7.4	7.0	1.8	125	19.1
Jan. 23	Feb. 1	150	97	.65	4.2	14	.8	22	4.8	5.0	.0	..	8.1	5.0	1.2	95	9.6
Feb. 2	Feb. 11	65	124	1.91	3.5	13	.16	13	4.0	3.8	5.8	45	8.1	.4	1.4	73	8.4
Feb. 12	Feb. 21	36	58	1.61	1.9	9.8	.09	18	3.8	5.5	14	40	8.9	.9	2.4	83	8.0
Feb. 22	Mar. 3	200	273	1.36	10	4.0	.15	18	3.4	4.3	12	46	8.9	1.8	2.0	78	10.1
Mar. 4	Mar. 13	210	172	.82	5.8	12	.35	19	3.6	6.2	.0	74	8.7	4.1	1.6	96	10.4
Mar. 14	Mar. 23	650	632	.97	23	21	.4	18	3.4	6.5	.0	70	8.2	4.0	1.3	100	13.0
Mar. 24	Apr. 2	43	36	.84	1.4	11	.12	21	4.0	5.7	2.9	73	8.2	2.8	2.4	92	6.7
Apr. 3	Apr. 12	90	65	.72	2.1	15	.18	18	3.2	6.9	.0	63	8.4	2.2	2.5	88	8.0
Apr. 14	Apr. 23	26	24	.92	1.4	22	.21	13	1.3	8.7	2.4	49	6.2	1.5	2.6	86	7.3
Apr. 24	May 3	24	28	1.17	0.5	12	.06	14	1.4	6.4	.0	59	7.7	.3	2.2	86	6.8
May 4	May 13	90	137	1.52	3.0	18	.10	18	3.0	7.9	.0	89	4.0	.5	1.4	100	9.0
May 14	May 23	49	52	1.06	1.9	34	.6	20	2.4	9.1	.0	82	7.6	2.0	1.9	131	7.2
May 25	June 3	26	28	1.08	.8	15	.10	21	3.8	7.9	2.9	77	7.7	1.5	2.4	102	6.7
June 4	June 13	375	357	.95	13	22	1.3	13	1.7	9.1	.0	51	7.2	1.8	2.4	106	9.4
June 14	June 24	215	237	1.10	5.6	16	.61	14	1.3	9.9	.0	54	11	1.5	1.4	93	8.3
June 26	July 5	68	69	1.02	2.3	12	.11	16	3.8	6.1	8.4	49	7.1	Tr.	1.8	81	6.3
July 7	July 16	40	75	1.88	1.8	16	.05	17	4.8	9.1	12	46	12	Tr.	2.2	85	6.4
July 17	July 26	190	103	.54	3.8	28	.52	17	....	9.9	8.4	58	12	.0	2.4	108	6.2
July 27	Aug. 5	33	53	1.60	1.4	7.8	.26	21	.....	6.6	17	41	9.9	.0	2.6	87	5.9
Aug. 6	Aug. 15	45	30	.67	2.1	16	.49	21	.....	7.5	.0	72	9.1	1.3	.6	96	5.7
Aug. 16	Aug. 25	20	16	.80	1.0	16	.16	22	.....	8.3	.0	78	9.4	1.2	3.6	99	6.1
Aug. 26	Sept. 4	70	39	.56	2.4	22	.70	22	.....	7.2	.0	78	8.7	1.3	3.0	112	6.4
Mean		150	142	.93	4.7	16	.49	21	3.7	6.8	2.4	73	8.3	2.5	2.0	104	..
Per ct. of anhydrous residue		....	....	....	....	16.1	[b].7	21.1	3.7	6.9	38.6	....	8.4	2.5	2.0	....	....

[a] Analyses August 28, 1906, to January 22, 1907, by R. B. Dole; January 23 to April 2, 1907, by R. B. Dole and M. G. Roberts; April 3 to July 5, 1907, by Chase Palmer and M. G. Roberts; July 7 to September 4, 1907, by R. B. Dole, Chase Palmer, and W. D. Collins.

[b] Fe_2O_3.

Mineral analyses of water from Lehigh River at South Bethlehem, Pa.[a]

[Parts per million, unless otherwise stated.]

Date (1906–7).		Turbidity.	Suspended matter.	Coefficient of fineness.	Total iron (Fe).	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.	Mean gage height (feet).[b]
From—	To—																
Sept. 11	Sept. 20	8	7.4	0.92	1.5	11	0.10	22	8.0	6.8	0.0	58	43	2.0	7.0	128	4.2
Sept. 21	Sept. 30	7	6	.86	.6	13	.5	23	8.8	9.1	.0	65	44	1.9	8.2	145	4.2
Oct. 1	Oct. 10	12	11	.92	.5	11	.10	17	7.0	7.9	.0	48	42	3.0	5.5	119	4.4
Oct. 11	Oct. 21	8	7.8	.98	.9	11	.10	17	6.6	7.7	.0	49	38	3.2	6.0	113	4.5
Oct. 22	Oct. 31	13	20	1.54	1.7	9.0	.20	12	4.8	6.9	.0	30	26	1.9	3.8	79	5.1
Nov. 1	Nov. 11	12	12	1.00	1.4	5.4	.06	12	4.6	5.8	.0	28	29	2.8	4.7	78	4.9
Nov. 12	Nov. 21	16	18	1.12	1.6	6.4	.08	12	4.8	6.1	.0	25	32	2.8	5.3	84	4.9
Nov. 23	Dec. 3	10	10	1.00	.8	10	.07	12	4.8	8.5	.0	34	29	3.0	6.2	88	4.9
Dec. 4	Dec. 13	13	11	.85	1.4	5.6	.06	13	5.6	5.2	.0	28	31	3.0	4.6	78	....
Dec. 14	Dec. 23	11	10	.91	1.0	6.4	.07	11	4.8	4.1	.0	28	26	3.8	5.0	72	4.9
Dec. 24	Jan. 2	50	107	2.14	3.2	7.0	.12	10	....	5.0	.0	28	25	4.0	5.4	68	....
Jan. 3	Jan. 13	17	34	2.00	1.9	8.0	.10	8.8	3.4	3.9	.0	22	20	4.0	3.8	60	5.4
Jan. 14	Jan. 25	13	22	1.69	1.8	9.6	.10	10	3.8	4.9	.0	27	21	4.0	3.7	68	5.2
Jan. 26	Feb. 4	11	11	1.00	1.1	7.2	.11	11	4.8	....	.0	29	27	3.0	4.8	72	....
Feb. 6	Feb. 15	9	4.6	.51	1.0	9.2	.09	13	5.4	5.0	.0	40	28	3.0	4.6	84	....
Feb. 16	Feb. 25	6	10	1.66	.8	6.2	.06	15	5.0	5.0	.0	44	25	2.1	3.6	83	....
Feb. 26	Mar. 7	11	9.0	.82	1.0	8.4	.04	16	5.4	8.5	.0	49	30	6.9	4.2	100	....
Mar. 8	Mar. 17	55	103	1.88	2.8	7.2	.10	13	....	4.5	.0	37	23	2.9	3.4	82	....
Mar. 18	Mar. 27	19	49	2.58	1.2	4.0	.09	7.6	1.6	5.8	.0	17	15	1.9	2.2	48	6.0
Mar. 28	Apr. 7	12	19	1.58	1.0	6.0	.09	11	2.2	4.6	.0	28	20	2.6	2.6	70	4.4
Apr. 8	Apr. 17	1	17	17.00	.9	4.6	.07	12	4.6	6.1	[c]9.6	17	23	.9	3.8	72	4.6
Apr. 18	Apr. 27	4	10	2.50	1.6	17	.10	13	5.0	....	.0	34	26	1.0	3.6	92	4.7
Apr. 28	May 7	2	7.2	3.60	1.0	12	.08	14	4.8	8.2	.0	36	25	1.0	3.8	86	4.5
May 8	May 17	18	20	1.11	1.0	7.6	.09	13	6.7	11	[c]16	13	30	.0	4.4	98	4.5
May 18	May 27	1	7.0	7.00	.6	15	.05	14	4.8	8.7	.0	45	25	.5	3.8	95	4.5
May 28	June 6	....	16	....	1.4	5.6	.06	12	4.5	7.6	.0	23	31	1.3	3.8	77	4.7
June 7	June 15	1	5.4	5.40	.7	10	.07	11	4.2	5.7	.0	32	23	1.5	3.6	76	4.7
June 17	June 26	2	15	7.50	.5	8.8	.05	13	4.2	7.6	.0	37	29	Tr.	4.4	85	4.5
June 27	July 6	3	19	6.33	.4	3.0	.05	14	5.0	6.9	[c]11	11	34	.2	4.2	83	4.6
July 7	July 17	4	4.8	1.20	.6	7.8	.04	14	6.0	7.2	.0	27	37	2.1	4.2	94	4.5
July 18	July 27	42	34	.81	1.8	....	.21	20	7.6	15	[c]4.8	57	37	1.8	5.8	174	4.3
July 28	Aug. 6	30	35	1.17	.9	....	.03	15	7.0	11	[c]2.4	35	39	.0	5.8	123	4.2
Aug. 7	Aug. 17	5	5.2	1.04	.6	10	.04	21	9.6	....	.0	56	38	1.8	7.0	127	4.3
Aug. 18	Aug. 27	4	4.8	1.20	.6	12	.13	24	10	12	.0	78	37	3.0	7.8	139	4.3
Aug. 28	Sept. 6	6	19	3.17	.8	15	.06	24	11	12	.0	78	37	2.2	8.4	147	4.2
Sept. 7	Sept. 16	....	....	....	1.8	....	.06	....	....	....	....	....	44	....	6.0	....	4.5
Sept. 17	Sept. 26	40	39	.98	2.4	....	.30	18	6.6	14	.0	66	31	.8	5.4	146	4.6
Mean		14	21	2.46	1.2	8.8	.10	14	5.7	7.5	.0	40	30	2.2	4.9	95	....
Per ct. of anhydrous residue		....	....	....	....	9.5	[d]1	15.0	6.1	8.1	21.2	....	32.3	2.4	5.3	....	....

[a] Analyses September 11 to October 31, 1906, by R. B. Dole; November 1, 1906, to April 7, 1907, by R. B. Dole and M. G. Roberts; April 8 to June 26, 1907, by Chase Palmer and M. G. Roberts; June 27, 1907, to September 26, 1907, by R. B. Dole, Chase Palmer, and W. D. Collins.

[b] Gaging station at Mauch Chunk, Pa., 30 miles above.

[c] Abnormal; computed as HCO_3 in the average.

[d] Fe_2O_3.

Mineral analyses of water from Maumee River at Toledo, Ohio.[a]

[Parts per million, unless otherwise stated.]

Date (1906–7). From—	To—	Turbidity.	Suspended matter.	Coefficient of fineness.	Total iron (Fe).	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.
Sept. 9	Sept. 18	55	46	0.84	2.0	28	0.10	58	17	44	0.0	178	44	2.2	91	397
Sept. 19	Sept. 29	70	55	.79	2.4	26	.20	57	16	40	.0	190	44	1.8	76	375
Sept. 30	Oct. 9	53	46	.87	2.4	19	.10	57	16	37	.0	192	43	1.8	71	350
Oct. 11	Oct. 20	37	30	.81	1.4	20	Tr.	67	19	36	.0	221	59	1.9	58	367
Oct. 21	Nov. 1	22	27	1.23	1.0	24	.04	66	22	40	.....	.....	68	1.7	79	416
Nov. 2	Nov. 11	16	14	.87	1.1	17	.03	73	23	49	5.8	208	71	2.1	106	442
Nov. 12	Nov. 23	80	84	1.05	2.2	14	.05	62	21	35	.....	.....	80	4.0	85	404
Nov. 24	Dec. 4	230	105	.46	3.5	16	.16	54	13	14	.0	157	48	19	23	275
Dec. 5	Dec. 15	290	590	2.04	6.6	23	.4	53	13	14	.0	159	47	13	24	277
Dec. 16	Dec. 26	210	112	.53	3.9	27	.3	57	14	18	5.8	160	51	12	24	296
Jan. 6	Jan. 15	350	235	.67	8.0	18	.7	42	8.2	10	.0	134	33	11	12	214
Jan. 16	Jan. 26	375	230	.61	11	17	1.1	37	.....	10	.0	123	29	9.0	12	193
Jan. 27	Feb. 7	55	43	.78	2.1	7.2	1.5	48	12	11	Tr.	151	37	4.5	14	262
Feb. 8	Feb. 18	20	22	1.10	.9	14	.13	77	18	22	5.5	228	69	8.5	38	372
Feb. 19	Feb. 28	12	9.2	.77	.6	15	.03	80	22	29	.0	242	74	6.0	58	410
Mar. 1	Mar. 10	37	29	.78	1.1	11	.04	70	19	25	.0	216	67	6.4	52	356
Mar. 11	Mar. 23	900	402	.45	16	36	.7	44	12	21	6.0	128	40	8.0	26	266
Mar. 24	Apr. 2	730	423	.58	15	5.0	.20	42	11	14	.0	131	41	6.4	13	222
Apr. 3	Apr. 12	98	133	1.36	3.3	6.0	.10	43	12	15	12	102	43	4.8	28	216
Apr. 13	Apr. 23	27	28	1.04	1.2	24	.08	72	18	20	11	210	57	6.0	30	344
Apr. 24	May 3	37	38	1.03	1.3	20	.06	74	20	25	9.6	214	63	3.0	44	373
May 4	May 14	9	13	1.45	.3	13	.03	64	18	25	9.6	178	59	2.5	46	326
May 15	May 23	42	58	1.38	1.0	9.8	.10	60	23	28	8.4	172	58	.3	44	320
May 25	June 3	20	47	2.35	.6	4.8	.08	.....	12	26	Tr.	93	50	.2	42	202
June 4	June 13	175	175	1.00	4.0	18	.18	.....	10	15	8.4	95	34	4.0	19	180
June 15	June 24	250	254	1.02	6.3	18	.18	.....	11	16	Tr.	120	34	Tr.	16	187
June 25	July 2	120	133	1.11	2.2	3.8	.16	.....	12	16	.....	.....	30	2.0	14	162
July 5	July 16	.....	.....	.....	1.9	.....	.12	35	16	26	Tr.	134	44	Tr.	35	232
July 17	July 26	270	195	.72	6.7	24	.6	52	13	24	.0	181	34	5.5	29	283
July 27	Aug. 5	63	61	.97	2.5	19	.7	44	9.0	14	.0	157	22	4.0	12	212
Aug. 6	Aug. 15	40	32	.80	1.2	18	.14	56	12	19	Tr.	199	33	2.2	23	267
Aug. 16	Aug. 26	40	32	.80	1.1	12	.11	64	16	21	.0	228	47	1.6	26	309
Aug. 27	Sept. 7	38	30	.79	1.5	14	.16	63	17	22	.0	224	50	2.2	26	310
Sept. 8	Sept. 17	38	30	.79	.7	22	.08	62	18	29	.0	229	53	1.0	34	339
Sept. 18	Sept. 27	125	122	.98	2.5	18	.6	52	16	23	.0	187	44	1.8	31	289
Sept. 28	Oct. 7	90	44	.49	1.6	22	.5	53	14	27	.0	177	42	2.0	41	292
Mean		143	112		3.4	17	.27	57	16	24	2.5	173	48	4.5	40	298
Per ct. of anhydrous residue		.....	.....	.95	.....	5.8	[b].1	19.4	5.4	8.2	29.7	.....	16.3	1.5	13.6	....

[a] Analyses September 9, 1906, to March 10, 1907, by R. B. Dole and M. G. Roberts; March 11 to October 7, 1907, by Chase Palmer and M. G. Roberts.

[b] Fe_2O_3.

Mineral analyses of water from Miami River at Dayton, Ohio.[a]

[Parts per million, unless otherwise stated.]

Date (1906–7).		Turbidity.	Suspended matter.	Coefficient of fineness.	Total iron (Fe).	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.	Mean gage height (feet).
From—	To—																
Sept. 16	Sept. 25	32	75	2.34	3.1	16	Tr.	58	28	10	9.0	264	38	0.9	5.0	300	0.7
Sept. 26	Oct. 5	32	58	1.81	.9	21	Tr.	65	28	9.0	9.0	280	35	2.8	5.8	318	.8
Oct. 6	Oct. 15	18	32	1.78	.4	17	Tr.	63	26	9.6	.0	297	37	3.1	5.0	309	.6
Oct. 16	Oct. 25	14	26	1.86	.10	18	Tr.	65	27	9.0	.0	301	40	2.9	5.0	317	.8
Oct. 26	Nov. 4	5	14	2.80	.15	20	Tr.	66	28	11	8.2	291	41	2.0	5.5	327	1.0
Nov. 5	Nov. 14	8	20	2.50	Tr.	20	Tr.	69	29	9.8	Tr.	317	41	2.0	5.3	335	2.0
Nov. 15	Nov. 24	75	89	1.19	2.1	14	0.24	64	27	9.8	11	250	40	7.0	4.3	304	2.8
Nov. 25	Dec. 4	16	21	1.31	.5	19	.05	75	28	7.4	3.6	278	60	15	4.0	346	2.4
Dec. 5	Dec. 14	26	34	1.31	.7	26	.07	75	28	8.2	10	269	62	12	4.7	355	2.5
Dec. 15	Dec. 24	80	54	.67	1.4	15	.23	64	23	6.8	.0	239	52	13	3.0	296	3.0
Dec. 25	Jan. 4	....	177	.....	3.2	16	.19	68	24	7.1	.0	272	52	12	3.5	318	4.2
Jan. 5	Jan. 14	210	118	.56	3.0	14	.5	50	17	6.5	.0	184	36	18	3.6	238	6.5
Jan. 15	Jan. 24	450	223	.50	6.7	15	.7	42	14	7.1	.0	161	29	11	3.4	212	7.5
Jan. 25	Feb. 4	75	49	.65	1.8	16	.6	61	23	8.8	12	229	44	16	4.1	301	3.3
Feb. 5	Feb. 14	45	42	.93	.5	8.8	.05	60	26	8.0	12	215	51	10	3.8	282	2.9
Feb. 15	Feb. 24	11	28	2.55	.4	24	.06	58	25	6.9	13	212	42	11	4.1	298	2.8
Feb. 25	Mar. 6	260	143	.55	4.2	25	.08	67	25	7.4	8.4	246	49	9.0	3.8	320	2.9
Mar. 27	Apr. 6	37	52	1.41	1.0	15	.12	64	24	8.0	12	228	44	10.0	4.6	299	2.2
Apr. 7	Apr. 16	25	67	2.68	.3	20	.14	50	26	8.4	12	200	44	15	5.4	282	2.1
Apr. 17	Apr. 26	25	32	1.28	.6	19	.11	58	25	3.5	16	217	41	15	4.2	298	2.2
Apr. 27	May 6	20	36	1.80	.4	15	.16	62	24	6.3	13	229	39	19	3.8	297	2.5
May 7	May 16	18	35	1.94	.4	23	.11	58	23	3.3	14	217	40	18	4.3	292	2.0
May 17	May 28	37	79	2.14	1.3	14	.10	52	26	3.0	12	218	41	15	3.8	275	1.8
May 29	June 8	240	186	.77	4.4	19	.19	53	20	12	10	197	34	15	4.8	264	3.8
June 9	June 18	280	252	.90	7.0	18	.7	49	18	11	9.6	180	27	17	3.8	252	5.2
June 19	June 28	75	75	1.00	2.6	17	.12	60	22	11	2.4	249	33	6.2	4.8	283	2.5
June 29	July 8	90	168	1.86	1.6	17	.03	42	26	8.2	.0	206	37	1.2	4.2	240	1.9
July 9	July 19	....	351	.....	7.9	30	.35	51	20	14	.0	.....	26	6.4	2.4	254	4.0
July 20	July 29	....	234	.....	3.2	8.6	.04	26	18	12	.0	.....	32	Tr.	.6	163	3.4
July 30	Aug. 8	....	125	.....	1.6	9.2	Tr.	56	24	12	.0	.....	37	1.5	.6	258	2.2
Aug. 9	Aug. 18	....	77	.....	1.0	18	.03	55	25	11	.0	.....	39	1.5	1.4	273	1.4
Aug. 19	Aug. 28	35	48	1.37	.9	9.8	.05	69	29	12	.0	323	34	.0	5.4	331	1.1
Aug. 29	Sept. 7	43	46	1.07	.9	15	.04	63	24	14	.0	287	41	2.5	5.8	304	1.2
Sept. 8	Sept. 17	140	130	.93	2.6	19	.13	59	25	13	.0	251	36	2.2	4.8	289	1.7
Mean		84	94	1.46	2.0	17	.15	59	24	9.0	5.8	244	40	8.6	4.1	289	....
Per ct. of anhydrous residue		.....	.....	.....	.....	5.9	[b].1	20.5	8.3	3.1	43.8	.....	13.9	3.0	1.4	.....	.....

[a] Analyses September 9 to December 4, 1906, by R. B. Dole; December 5, 1906, to March 6, 1907, by R. B. Dole and M. G. Roberts; March 27 to June 28, 1907, by Chase Palmer and M. G. Roberts; June 29 to September 17, 1907, by R. B. Dole, Chase Palmer, and W. D. Collins.

[b] Fe_2O_3.

Mineral analyses of water from Lake Michigan at St. Ignace, Mich.[a]

[Parts per million, unless otherwise stated.]

Date (1906-7).	Turbidity.	Suspended matter.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.	Mean gage height (feet).[b]
Sept. 20	1	....	17	0.02	27	7.7	4.9	5.9	109	6.6	0.20	2.6	126	581.08
Oct. 20	1	....	9.2	.02	26	7.4	4.4	6.6	103	6.5	.30	2.6	115	580.85
Nov. 20	Tr.	....	9.5	.05	28	8.8	3.4	2.4	117	6.4	.35	2.9	120	580.72
Dec. 20	1	....	10	.06	25	7.1	4.7	1.6	104	6.2	Tr.	2.6	108	580.62
Jan. 20	1	....	6.2	.04	26	8.1	3.2	1.6	110	6.2	.4	2.8	110	580.67
Feb. 19	....	....	12	.03	26	8.4	5.4	3.4	113	7.6	.35	2.8	120	580.64
Mar. 20	....	....	14	.03	25	7.9	5.0	Tr.	111	7.9	.4	2.6	117	580.67
Apr. 21	....	....	8.4	.04	26	8.1	4.7	.0	112	9.5	.3	2.4	115	580.83
May 20	....	....	9.5	.03	27	8.7	5.4	2.6	115	7.8	.25	2.5	121	581.07
June 20	....	....	8.6	.04	26	8.4	6.6	4.5	116	7.7	.55	3.0	120	581.42
Aug. 20	....	....	11	.04	28	9.4	4.2	3.5	120	7.4	.4	3.2	123	581.51
Mean	Tr.	Tr.	10	.04	26	8.2	4.7	2.9	112	7.2	0.3	2.7	118	.....
Per ct. of anhydrous residue	....	....	8.5	[c].0	22.2	7.0	4.0	49.6	.....	6.1	0.3	2.3	.....	.....

[a] Analyses by R. B. Dole and M. G. Roberts.
[b] Gaging station at Mackinaw, Mich., 5 miles away.
[c] Fe_2O_3.

Mineral analyses of water from Minnesota River at Shakopee, Minn.[a]

[Parts per million, unless otherwise stated.]

Date (1906-7).		Turbidity.	Suspended matter.	Coefficient of fineness.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.	Mean gage height (feet).[b]
From—	To—															
Sept. 24	Oct. 4	110	124	1.13	28	0.05	68	33	20	0.0	270	123	1.8	3.5	419	6.6
Oct. 6	Oct. 18	75	83	1.11	28	Tr.	77	40	21	[c]9.6	317	126	1.8	4.2	469	4.6
Oct. 19	Oct. 30	60	61	1.02	24	.10	82	.....	33	.0	331	134	1.3	6.5	477	4.6
Oct. 31	Nov. 10	80	110	1.38	29	Tr.	84	38	27	.0	287	184	1.5	3.5	536	6.4
Nov. 12	Nov. 22	70	74	1.06	29	.05	86	37	25	.0	329	171	.9	4.1	533	5.7
Nov. 23	Dec. 4	70	76	1.08	20	.05	97	39	32	.0	366	182	.9	4.5	580	4.7
Dec. 5	Jan. 1	20	20	1.00	24	Tr.	116	.....	33	.0	444	215	2.6	7.5	696	4.6
Jan. 2	Jan. 12	10	8.0	.80	22	.05	150	58	.....	.0	459	206	1.4	8.7	688	3.4
Jan. 14	Jan. 24	10	4.0	.40	26	Tr.	121	55	30	.0	.....	205	1.4	11	692	3.2
Jan. 25	Feb. 6	5	.....	.....	24	Tr.	126	57	.....	.0	489	211	1.3	.....	722	2.8
Feb. 7	Feb. 21	10	.....	.....	28	Tr.	102	48	39	.0	415	177	5.5	10	609	3.8
Feb. 22	Mar. 5	10	12	1.20	16	Tr.	59	26	22	.0	201	94	2.8	4.8	337	6.0
Mar. 6	Mar. 16	10	.....	.....	18	.03	69	22	20	.0	222	118	2.3	1.4	384	4.6
Mar. 19	Mar. 29	275	422	1.54	19	.40	43	19	15	.0	154	66	1.9	2.0	250	7.8
Mar. 30	Apr. 10	110	142	1.29	13	.18	45	19	14	.0	178	82	1.8	2.0	288	9.4
Apr. 11	Apr. 21	.....	132	.....	11	.15	50	25	23	.0	212	107	1.3	.....	359	7.6
Apr. 22	Apr. 30	50	.....	.....	22	Tr.	72	33	22	.0	266	128	7.8	2.9	439	5.7
May 3	May 14	30	.....	.....	14	.01	99	42	26	.0	294	180	Tr.	3.7	527	5.3
May 15	May 25	30	.....	.....	16	.05	94	43	20	.0	320	203	1.8	3.4	588	4.9
May 28	June 6	80	112	1.40	20	.18	91	40	18	.0	284	177	1.9	2.5	553	6.3
June 7	June 18	175	288	1.64	26	.20	78	34	17	.0	261	153	1.6	1.7	482	9.8
June 19	June 29	105	158	1.50	30	.10	77	32	19	.0	278	137	1.2	.....	447	13.1
July 1	July 12	80	144	1.80	27	.08	78	37	21	.0	310	140	3.4	3.6	477	8.7
July 13	July 24	330	371	1.12	28	.15	71	31	27	.0	287	114	2.7	7.4	419	7.2
July 25	Aug. 5	155	236	1.52	27	.03	71	31	11	.0	279	112	2.2	.....	408	6.3
Aug. 7	Aug. 17	155	180	1.16	30	.05	82	37	27	.0	334	133	1.5	5.8	481	3.8
Aug. 19	Aug. 29	240	256	1.08	25	.04	66	30	21	.0	271	106	1.6	5.0	408	3.8
Aug. 30	Sept. 9	140	.....	.....	.....	.05	66	29	15	.0	236	126	.4	1.9	397	4.2
Sept. 10	Sept. 20	140	113	.81	32	.04	77	32	19	[c]6.0	272	112	1.4	8.2	437	3.0
Sept. 21	Oct. 1	165	141	.85	23	.6	58	19	.....	.0	200	94	1.5	3.0	312	4.0
Mean		97	142	1.18	23	.09	82	35	23	.0	296	144	2.0	4.7	480	....
Per ct. of anhydrous residue		.....	.....	.....	5.0	*d*.0	17.9	7.6	5.0	31.7	.....	31.4	.4	1.0	.....	.....

[a] Analyses September 24, 1906, to February 6, 1907, by W. M. Barr; February 7 to March 5, 1907, by H. S. Spaulding; March 6 to September 9, 1907, by Walton Van Winkle; September 10 to October 1, 1907, by R. B. Dole, Chase Palmer, and W. D. Collins.

[b] Gaging station at Mankato, Minn., 60 miles above.

[c] Abnormal; computed as HCO_3 in the average.

[d] Fe_2O_3.

Mineral analyses of water from Mississippi River at Minneapolis, Minn.[a]

[Parts per million, unless otherwise stated.]

Date (1906–7).		Turbidity.	Suspended matter.	Coefficient of fineness.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3)	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.	Mean gage height (feet).[b]
From—	To—															
Sept. 10	Sept. 19	25	19	0.76	33	0.10	.....	13	15	0.0	204	8.2	0.8	0.9	225	1.7
Sept. 20	Sept. 30	10	33	3.30	30	.10	40	15	14	.0	182	20	.9	2.5	209	2.5
Oct. 1	Oct. 10	15	29	1.93	19	.10	38	.....	15	.0	.....	14	5.2	3.8	194	3.0
Oct. 11	Oct. 21	10	13	1.30	22	.05	41	16	10	.0	196	25	.4	2.5	191	2.0
Oct. 22	Oct. 31	10	7.4	.74	21	Tr.	42	15	9.2	.0	189	27	.3	2.0	203	2.2
Nov. 1	Nov. 10	15	13	.87	13	Tr.	38	16	11	.0	.....	18	Tr.	1.0	187	2.8
Nov. 11	Nov. 21	10	10	1.00	12	.05	43	16	11	.0	.....	20	.7	1.6	206	2.6
Nov. 22	Dec. 1	5	6.0	1.20	12	.08	46	15	9.9	.0	215	25	.9	2.0	220	4.7
Dec. 2	Dec. 12	10	6.4	.64	13	.10	46	16	7.6	.0	218	23	1.8	1.9	220	9.6
Dec. 13	Dec. 24	5	Tr.	.....	16	.06	47	17	9.8	.0	214	28	.9	1.7	236	....
Dec. 25	Jan. 4	5	Tr.	.....	17	Tr.	47	.....	13	.0	208	20	.9	1.5	217	....
Jan. 5	Jan. 15	5	Tr.	.....	15	Tr.	41	14	7.5	.0	222	.....	1.3	1.7	213	....
Jan. 16	Jan. 26	10	2.4	.24	14	.06	46	16	11	.0	222	18	1.1	2.0	206	....
Jan. 27	Feb. 6	5	Tr.	.....	16	.10	45	18	8.2	.0	222	.....	1.6	1.9	217	....
Feb. 7	Feb. 16	5	Tr.	.....	13	.10	.....	16	12	.0	220	12	2.0	1.9	214	....
Feb. 17	Feb. 26	5	4.0	.80	16	.05	46	14	16	.0	205	24	7.0	2.3	221	....
Feb. 27	Mar. 8	5	2.4	.48	17	.05	43	16	17	.0	222	23	4.6	1.5	218	....
Mar. 9	Mar. 18	10	.....	.....	11	.....	46	.....	9.8	.0	195	15	2.9	2.0	207	....
Mar. 19	Mar. 28	15	29	1.93	12	.05	.....	.....	9.6	.0	147	9.2	1.9	2.2	155	....
Mar. 30	Apr. 8	30	30	1.00	9.0	.25	27	8.8	6.5	.0	127	17	1.2	.3	132	6.2
Apr. 9	Apr. 19	10	Tr.	.....	9.0	.01	26	9.8	7.3	.0	127	20	1.1	.4	160	4.5
Apr. 20	Apr. 29	5	Tr.	.....	15	.15	34	12	8.0	.0	144	20	Tr.	1.5	183	3.1
Apr. 30	May 13	5	Tr.	.....	12	.04	33	13	7.0	.0	156	20	1.9	.....	180	2.3
May 14	May 23	7	.....	.....	15	.02	39	13	.....	.0	178	18	.6	.2	209	1.7
May 24	June 2	5	Tr.	.....	12	.05	35	12	7.9	.0	165	22	.8	.....	205	2.9
June 3	June 13	8	.....	.....	14	Tr.	.....	12	5.2	.0	159	19	1.2	.6	180	3.3
June 14	June 23	5	Tr.	.....	12	.15	37	13	5.7	.0	171	23	1.3	3.3	233	4.0
June 24	July 3	20	.....	.....	18	Tr.	41	15	6.4	.0	193	16	1.1	1.2	221	2.6
July 4	July 13	20	24	1.20	20	.05	44	.....	11	.0	.....	15	1.6	3.1	206	1.3
July 14	July 23	5	Tr.	.....	8.6	.08	44	10	13	.0	198	8.6	.6	Tr.	198	1.0
July 24	Aug. 2	10	.....	.....	5.2	.13	43	11	12	.0	206	14	1.1	1.0	197	.8
Aug. 3	Aug. 12	5	Tr.	.....	13	.11	40	14	11	.0	199	14	T.	1.4	187	.7
Aug. 13	Aug. 22	10	7.6	.76	17	.10	38	14	7.5	.0	173	13	.4	.4	185	1.1
Aug. 23	Sept. 1	5	Tr.	.....	19	.18	35	12	9.0	.0	172	10	.4	1.5	175	1.4
Sept. 2	Sept. 11	5	Tr.	.....	15	.11	37	12	11	.0	185	14	Tr.	.5	173	.6
Mean.....		10	7.9	1.13	15	.07	40	14	10	.0	188	18	1.4	1.6	200	....
Per ct. of anhydrous residue.....		.....	.....	.....	7.8	c.1	20.8	7.3	5.2	48.0	.....	9.3	.7	.8	.....	.....

[a] Analyses September 10, 1906, to February 16, 1907, by W. M. Barr; February 17 to 26, 1907, by H. S. Spaulding; February 27 to September 11, 1907, by Walton Van Winkle.

[b] Gaging station at Anoka, Minn., 20 miles above.

[c] Fe_2O_3.

Mineral analyses of water from Mississippi River at Memphis, Tenn.[a]

[Parts per million, unless otherwise stated.]

Date (1907–8).		Turbidity.	Suspended matter.	Coefficient of fineness.	Total iron (Fe).	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.	Mean gage height (feet).
From—	To—																
Jan. 10	Jan. 20	420	353	0.84	.....	40	0.7	...	14	....	0.0	146	....	0.3	6.0	198	32.8
Jan. 21	Jan. 30	350	239	.68	.....	39	.7	32	17	....	.0	129	....	.5	7.0	209	34.9
Jan. 31	Feb. 9	340	264	.78	.....	34	.20	...	.....	....	.0	82	....	.4	7.0	168	39.5
Feb. 10	Feb. 19	270	216	.80	.....	37	.7	29	9.0	....	.0	90	....	.5	5.5	165	28.7
Feb. 20	Mar. 1	420	324	.77	.....	36	1.2	32	18	....	.0	112	....	.6	7.0	186	18.0
Mar. 2	Mar. 11	425	355	.84	.....	34	.8	43	17	....	.0	112	....	.5	10	205	25.8
Mar. 12	Mar. 21	680	615	.90	.....	43	.7	....	12	....	.0	102	....	.3	9.5	172	29.7
Mar. 22	Mar. 31	550	505	.92	.....	40	.7	....	10	....	.0	90	....	.9	9.5	162	34.2
Apr. 1	Apr. 10	960	740	.77	.....	34	1.3	37	12	....	.0	115	....	.2	12	188	32.9
Apr. 11	Apr. 20	680	485	.71	.....	22	1.3	27	11	....	.0	115	....	1.6	6.5	156	23.6
Apr. 21	Apr. 30	550	415	.76	.....	24	1.4	29	8.4	....	.0	104	....	1.8	8.0	161	21.5
May 1	May 10	1,150	816	.71	.....	31	2.8	24	15	....	.0	95	....	1.1	9.0	174	24.7
May 11	May 20	375	386	1.03	.....	31	1.6	26	9.7	13	.0	95	36	2.9	5.0	188	30.8
May 21	May 30	485	484	1.00	.....	19	1.1	30	7.7	13	.0	93	36	5.5	5.1	169	25.8
May 31	June 9	420	332	.79	.....	10	.12	....	12	13	.0	122	46	5.3	6.3	188	19.2
June 11	June 20	1,600	1,421	.89	.....	19	.05	42	12	....	.0	153	63	4.9	5.9	247	27.3
June 21	June 30	1,300	1,161	.89	.....	12	1.6	36	14	....	.0	....	53	4.9	5.5	231	28.2
July 1	July 10	1,400	1,244	.89	.....	16	.18	46	11	28	.0	156	56	5.3	8.7	245	21.9
July 11	July 20	1,000	1,185	1.18	.....	13	.30	49	15	21	.0	....	67	2.2	6.0	246	17.8
July 21	July 30	425	1,389	3.26	.....	14	.11	41	12	28	.0	172	67	2.4	12	250	22.9
July 31	Aug. 9	900	797	.89	.....	16	.08	37	9.3	24	.0	143	41	1.8	9.0	205	22.9
Aug. 10	Aug. 19	950	888	.93	.....	21	.20	39	12	21	.0	144	52	4.0	6.8	220	17.0
Aug. 20	Aug. 29	600	.....	.....	.....	22	.13	41	13	21	.0	149	47	4.6	8.0	236	14.8
Aug. 30	Sept. 8	600	451	.75	.....	17	.17	36	12	22	.0	144	40	1.7	8.5	207	14.1
Sept. 9	Sept. 18	280	307	1.10	10	22	.16	38	12	17	[b]8.4	130	33	1.2	8.4	204	11.8
Sept. 19	Sept. 28	270	316	1.17	10	24	.14	39	12	13	[b]7.2	146	34	Tr.	11	218	10.1
Sept. 29	Oct. 8	220	203	.92	7.4	23	.22	39	10	20	[b]7.2	145	37	Tr.	9.8	219	10.0
Oct. 9	Oct. 18	240	221	.92	8.8	14	.5	35	10	16	Tr.[b]	142	34	Tr.	9.4	198	10.9
Oct. 19	Oct. 28	270	198	.73	11	21	.37	36	13	17	[b]7.2	134	34	.20	9.6	208	9.9
Oct. 29	Nov. 9	240	316	1.32	8.8	20	.12	43	13	18	[b]3.6	159	40	Tr.	11	235	7.0
Nov. 10	Nov. 19	230	203	.88	7.9	21	.52	42	13	28	[b]7.2	159	39	Tr.	14	257	9.0
Nov. 20	Dec. 1	230	215	.93	13	10	.42	36	11	18	Tr.[b]	127	43	Tr.	16	200	12.0
Dec. 2	Dec. 12	180	187	1.04	8.0	5.6	.07	33	10	14	[b]8.4	106	29	Tr.	9.0	162	11.6
Dec. 13	Dec. 22	170	160	.94	3.5	24	.24	36	12	17	[b]13	115	32	1.7	9.6	201	8.4
Dec. 23	Jan. 1	265	265	1.00	7.9	26	.56	33	10	16	Tr.[b]	124	35	1.5	9.6	195	13.5
Mean		556	519	.97	.....	24	.61	36	12	19	.0	129	43	1.7	8.6	202	.....
Per ct. of anhydrous residue		.....	.....	.....	.....	11.5	[c].4	17.3	5.7	9.1	30.5	....	20.6	.8	4.1	....	.....

[a] Analyses January 10 to May 10, 1907, by Jas. R. Evans; May 11 to September 8, 1907, by Walton Van Winkle; September 9, 1907, to January 1, 1908, by R. B. Dole, Chase Palmer, and W. D. Collins.

[b] Abnormal; computed as HCO_3 in the average.

[c] Fe_2O_3.

Mineral analyses of water from Mississippi River at New Orleans, La.[a]

[Parts per million, unless otherwise stated.]

Date (1905-6).		Silica (SiO_2).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.	Free carbon dioxide (CO_2).	Mean gage height (feet).[b]
From—	To—														
Apr. 29	May 6	9.5	0.11	0.63	29	7.5	12	.....	98	22	2.1	9.2	145	13	10.5
May 7	May 13	8.2	.12	.44	28	6.7	13	.....	100	23	2.1	11	150	25	10.6
May 14	May 20	8.6	.10	.72	32	7.9	14	.....	100	27	2.1	10	157	15	11.9
May 21	May 27	8.8	.25	.42	30	7.1	19	.....	103	23	2.1	11	158	38	12.3
May 28	June 3	8.8	.10	.54	33	7.7	19	.....	110	25	2.1	8.3	166	22	13.2
June 4	June 10	11	.06	.59	31	7.1	14	.....	105	24	2.1	7.5	156	16	13.9
June 11	June 17	12	.10	.72	33	7.3	12	.....	115	23	2.0	7.3	157	8.0	13.7
June 18	June 24	14	.12	.76	34	8.1	14	.....	122	24	2.0	9.8	176	15	12.3
June 25	July 1	14	.06	.67	35	8.9	14	.....	125	25	2.0	9.4	178	44	10.9
July 2	July 8	11	.11	.34	35	9.0	15	.....	125	30	2.8	9.9	185	9	10.7
July 9	July 15	11	.13	.30	34	8.5	18	.....	116	36	2.8	7.7	182	47	11.5
July 16	July 22	10	.12	.20	33	8.1	18	.....	110	35	2.7	12	183	30	11.9
July 23	July 29	12	.11	.29	32	7.7	15	.....	108	28	2.6	7.6	168	3	11.4
July 30	Aug. 5	13	.13	.32	33	8.5	21	.....	116	36	2.7	10	195	47	11.2
Aug. 6	Aug. 12	15	.15	.27	32	7.8	16	.....	111	29	2.3	10	180	32	10.3
Aug. 13	Aug. 20	11	.27	.40	32	8.0	19	.....	115	27	2.3	11	179	15	9.1
Aug. 21	Aug. 26	12	.26	.23	32	8.2	14	.....	115	24	2.4	8.0	169	17	7.4
Aug 27	Sept. 2	11	.30	.28	33	8.7	17	.....	122	26	2.5	13	185	20	7.4
Sept. 3	Sept. 9	11	.21	.24	33	9.0	21	.....	120	29	2.4	17	199	62	7.3
Sept. 10	Sept. 16	10	.10	.43	32	8.8	16	.....	118	26	2.3	10	181	20	4.8
Sept. 17	Sept. 23	13	.15	.53	34	9.1	15	.....	126	24	2.5	10	195	51	3.2
Sept. 24	Sept. 30	16	.21	.93	39	10	21	.....	132	30	2.4	18	210	21	4.8
Oct. 1	Oct. 7	16	.10	.43	33	8.9	17	.....	117	27	2.6	12	190	13	7.6
Oct. 8	Oct. 14	10	.09	.33	30	6.8	13	.....	106	18	2.3	7.8	157	22	5.4
Oct. 15	Oct. 21	12	.08	.55	33	8.7	14	.....	118	20	2.3	8.8	170	20	2.8
Oct. 22	Oct. 28	12	.09	.36	39	11	15	.....	140	23	2.2	11	192	10	1.9
Oct. 29	Nov. 4	13	.10	.27	42	12	15	.....	151	25	3.0	11	210	19	3.5
Nov. 5	Nov. 11	9.3	.09	.41	34	10	14	.....	123	22	2.8	11	168	31	5.2
Nov. 12	Nov. 18	10	.08	.41	32	9.0	11	.....	115	21	3.2	9.4	158	30	5.1
Nov. 19	Nov. 25	9.6	.11	.29	35	10	12	.....	117	23	3.0	11	169	39	4.7
Nov. 26	Dec. 2	11	.08	.42	33	9.5	13	.....	126	25	2.8	11	181	23	3.5
Dec. 3	Dec. 9	12	.11	.37	39	12	16	.....	142	24	2.8	15	207	23	2.8
Dec. 10	Dec. 16	9.4	.15	.18	42	12	16	.....	145	29	2.7	14	215	24	5.7
Dec. 17	Dec. 23	8.0	.13	.28	33	9.1	11	.....	115	22	3.0	9.5	172	33	8.4
Dec. 24	Dec. 30	6.8	.13	.32	29	7.6	11	.....	94	20	2.8	11	149	39	7.5
Jan. 1	Jan. 6	9.2	.12	.47	31	7.8	11	.....	98	20	2.3	11	150	18	8.0
Jan. 7	Jan. 13	9.2	.10	.38	31	8.0	9.4	.....	100	18	2.5	8.2	148	26	8.9
Jan. 14	Jan. 20	7.6	.09	.25	32	8.0	11	.....	102	23	2.7	11	157	28	10.5
Jan. 21	Jan. 27	9.2	.11	.37	28	6.7	8.3	.....	92	19	2.6	6.5	136	46	10.7
Jan. 28	Feb. 3	9.2	.12	.33	29	7.0	8.5	.....	91	18	2.7	8.2	138	44	11.4
Feb. 4	Feb. 10	7.8	.10	.29	28	6.8	7.8	.....	91	17	2.5	6.3	130	50	12.5
Feb. 11	Feb. 17	9.8	.11	.34	27	6.6	7.8	.....	85	18	2.3	6.8	131	37	12.4
Feb. 18	Feb. 24	11	.10	.27	28	7.0	8.4	.....	91	18	2.2	7.0	139	35	10.3
Feb. 25	Mar. 3	9.2	.10	.32	30	8.1	9.7	.....	105	18	2.2	8.0	150	31	7.3
Mar. 4	Mar. 10	13	.12	.44	35	10	11	.....	125	21	2.7	10	168	33	7.1
Mar. 11	Mar. 17	10	.10	.35	35	10	10	.....	116	26	2.8	8.7	165	48	9.8
Mar. 18	Mar. 24	12	.18	.50	30	8.0	9.6	.....	96	22	2.9	8.4	144	44	11.6
Mar. 25	Mar. 31	11	.15	.42	31	8.0	9.4	.....	98	21	2.8	7.3	145	45	8.0
Apr. 1	Apr. 7	9.2	.15	.37	30	7.8	9.5	.....	98	20	2.9	9.0	142	42	12.5
Apr. 8	Apr. 14	9.3	.14	.29	29	7.2	7.9	.....	91	18	2.1	5.3	132	52	13.4
Apr. 15	Apr. 21	8.0	.13	.35	27	7.0	8.3	.....	92	17	3.0	4.8	130	41	14.2
Apr. 22	Apr. 28	11	.13	.24	29	7.2	9.9	.....	92	20	2.5	6.1	137	45	15.5
Mean		11	c.13	c.40	32	8.4	13	.0	111	24	2.5	9.7	166	.....	.....
Per ct. of anhydrous residue		7.1	c.1	c.5	20.6	5.4	8.4	34.7	.....	15.4	1.6	6.2	.....	.....	.....

[a] Analyses by J. S. Porter, chemist, New Orleans water and sewerage board.
[b] Gaging station at Carrollton, La., 5 miles above.
[c] $Fe_2O_3+Al_2O_3$.

Mineral analyses of water from Missouri River near Florence, Nebr.[a]

[Parts per million, unless otherwise stated.]

Date (1906–7.) From–	Date (1906–7.) To–	Turbidity.	Suspended matter.	Coefficient of fineness.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.	Mean gage height (feet).[b]
Oct. 1	Oct. 10	2,400	2,776	1.16	30	0.20	53	17	57	0.0	.....	197	1.3	8.0	442	7.1
Oct. 11	Oct. 20	1,080	911	.84	18	.05	88	37	34	.0	215	178	.9	8.7	467	6.2
Oct. 21	Oct. 31	880	1,303	1.48	44	.6	68	25	72	.0	.....	175	.3	9.0	496	6.7
Nov. 1	Nov. 10	1,470	1,495	1.02	36	.5	73	25	53	.0	231	184	1.0	8.7	526	6.4
Nov. 11	Nov. 20	625	730	1.17	27	.5	82	30	57	.0	247	195	.9	9.1	543	5.8
Nov. 21	Nov. 30	350	460	1.32	29	.20	94	30	45	.0	298	212	1.8	9.5	597	5.1
Dec. 2	Dec. 13	325	352	1.08	24	.18	92	38	51	.0	305	211	.9	12	565	4.7
Dec. 14	Dec. 23	80	80	1.00	25	.10	102	38	58	.0	337	237	1.0	12	663	3.7
Dec. 25	Jan. 3	90	80	.89	23	.05	91	33	52	.0	300	222	.9	14	608	.....
Jan. 4	Jan. 13	120	140	1.17	23	.05	82	30	.....	.0	270	199	.9	14	545	.....
Jan. 15	Jan. 26	230	220	.96	28	.10	97	27	60	.0	309	233	1.4	15	615	.....
Jan. 27	Feb. 6	40	68	1.70	34	Tr.	96	32	60	.0	310	224	1.6	15	620	.....
Feb. 7	Feb. 16	110	83	.75	27	.15	80	27	50	.0	251	178	1.5	12	499	.....
Feb. 17	Feb. 27	1,400	2,691	1.92	36	1.2	50	13	38	.0	154	132	1.6	6.2	340	.....
Feb. 28	Mar. 12	750	1,520	2.03	37	1.4	56	13	38	.0	156	143	2.6	5.5	403	10.4
Mar. 14	Mar. 23	2,700	2,854	1.06	39	2.0	51	18	38	.0	156	144	2.9	8.7	393	12.6
Mar. 24	Apr. 2	2,700	2,968	1.10	16	1.0	45	10	62	.0	160	153	1.2	10	394	12.0
Apr. 3	Apr. 12	3,330	3,511	1.06	43	.7	54	15	49	.0	176	128	1.2	7.1	402	12.2
Apr. 14	Apr. 23	3,600	4,071	1.13	55	1.2	61	.....	58	.0	162	204	1.5	6.9	540	12.8
Apr. 25	May 4	3,800	4,026	1.06	67	.65	53	.....	56	.0	152	217	1.2	6.0	548	11.5
May 5	May 14	3,100	2,514	.81	21	.35	52	17	50	.0	163	154	3.6	6.9	390	11.0
May 15	May 24	1,460	1,624	1.11	41	.8	56	18	43	.0	177	167	1.1	8.2	435	10.3
May 25	June 3	7,200	7,726	1.08	16	.10	58	16	56	.0	164	197	1.7	4.6	455	14.0
June 4	June 13	4,000	5,900	1.47	10	.18	58	16	56	.0	164	190	3.8	6.2	444	14.8
June 14	June 24	2,800	4,286	1.53	76	1.2	59	.....	50	.0	162	180	3.8	6.1	530	15.9
June 25	July 4	3,200	3,203	1.00	21	.07	61	12	40	.0	166	.....	1.8	5.0	.....	15.8
July 5	July 14	4,000	5,554	1.39	20	.9	51	16	51	.0	152	179	3.1	.....	416	16.6
July 15	July 24	3,600	2,977	.83	16	.13	50	12	44	.0	161	113	5.0	7.0	325	16.9
July 25	Aug. 3	1,600	1,816	1.14	19	.04	49	7.9	50	.0	171	108	5.5	7.6	340	15.2
Aug. 4	Aug. 13	2,000	1,989	.99	21	.05	47	14	44	.0	163	110	2.0	14	326	13.3
Aug. 14	Aug. 23	1,000	1,180	1.18	26	.04	66	20	37	.0	262	81	1.6	6.0	353	11.9
Aug. 24	Sept. 3	900	1,580	1.75	25	.38	46	14	36	.0	146	96	.9	8.8	300	10.6
Sept. 4	Sept. 13	1,200	968	.81	33	.06	48	13	42	.0	158	115	.9	7.0	322	9.7
Sept. 14	Sept. 23	1,000	847	.85	36	.10	48	13	40	[c]4.8	146	113	.7	8.4	332	9.2
Sept. 24	Oct. 3	900	812	1.16	35	.35	54	17	44	[c]7.2	150	.....	Tr.	7.8	362	8.8
Oct. 4	Oct. 14	1,000	797	.80	33	.14	54	14	46	[c]4.8	161	134	1.2	9.6	373	8.5
Mean		1,726	2,059	1.16	31	.44	65	20	49	.0	203	168	1.8	8.9	454	.....
Per ct. of anhydrous residue		.....	.....	.....	7.0	[d].2	14.6	4.5	11.0	22.5	.....	37.8	.4	2.0	.....	.....

[a] Analyses October 1, 1906, to February 6, 1907, by W. M. Barr; February 17 to 27, 1907, by H. S. Spaulding; February 28 to September 13, 1907, by Walton Van Winkle; September 14 to October 14, 1907, by R. B. Dole, Chase Palmer, and W. D. Collins.

[b] Gaging station near Omaha, Nebr., 5 miles below.

[c] Abnormal; computed as HCO_3 in the average.

[d] Fe_2O_3.

Mineral analyses of water from Missouri River near Kansas City, Kans.[a]

[Parts per million, unless otherwise stated.]

Date. (1906–7.)		Turbidity.	Suspended matter.	Coefficient of fineness.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.	Mean gage height (feet).[b]
From—	To—															
Oct. 4	Oct. 13	2,500	2,231	0.89	31	0.30	60	19	49	0.0	198	138	2.2	13	419	8.5
Oct. 14	Oct. 23	900	942	1.05	26	Tr.	69	21	40	.0	215	154	.4	13	438	7.2
Oct. 24	Nov. 2	1,230	1,680	1.36	33	.5	64	21	.....	.0	217	128	2.2	15	426	8.7
Nov. 3	Nov. 12	1,500	1,470	.98	31	.40	69	22	49	.0	219	150	2.2	13	447	9.0
Nov. 13	Nov. 22		870	840	.97	38	.40	75	24	50	.0	236	164	.9	13	486	8.6
Nov. 23	Dec. 2		475	577	1.21	30	.20	77	22	53	.0	270	158	.4	15	495	7.6
Dec. 3	Dec. 12		500	547	1.09	38	.40	77	21	.....	.0	275	146	1.8	17	510	7.0
Dec. 13	Dec. 22		300	319	1.06	30	.40	85	27	51	.0	307	175	.9	20	525	4.5
Dec. 23	Jan. 2		190	222	1.17	41	.12	91	29	55	.0	334	.....	1.3	22	580	4.5
Jan. 3	Jan. 12		350	374	1.07	39	.40	78	26	49	.0	265	158	2.6	18	503	7.4
Jan. 13	Jan. 22		270	247	.91	35	.35	79	23	52	.0	265	159	3.1	18	493	6.3
Jan. 23	Feb. 2		140	96	.69	41	.08	90	30	55	.0	326	176	2.2	23	579	5.1
Feb. 3	Feb. 12		35	24	.68	43	.20	84	28	68	.0	328	167	2.2	24	590	5.2
Feb. 13	Feb. 22	1,020	1,316	1.29	70	2.8	61	22	61	.0	.....	.....	4.4	16	454	10.2
Feb. 23	Mar. 5	1,400	1,730	1.24	74	.20	56	17	43	.0	156	.....	1.7	8.5	414	13.5
Mar. 6	Mar. 15	1,500	1,896	1.26	41	1.4	52	15	37	.0	164	122	3.4	9.5	392	12.0
Mar. 16	Mar. 25	3,450	2,867	.83	65	2.1	.....	.....	39	.0	164	123	1.9	11	435	13.5
Mar. 26	Apr. 4	2,150	2,619	1.22	55	2.1	.....	10	41	.0	157	.....	2.5	6.3	362	12.7
Apr. 5	Apr. 14	2,800	2,826	1.01	62	2.4	53	15	42	.0	168	137	2.2	8.7	440	13.1
Apr. 15	Apr. 24	3,600	3,496	.97	41	.5	68	11	55	.0	162	179	3.0	9.5	462	13.2
Apr. 25	May 4	3,800	3,938	1.04	89	1.8	.....	20	60	.0	.....	171	Tr.	11	549	12.0
May 5	May 14	2,800	2,350	.84	47	3.2	.....	16	48	.0	160	176	5.3	11	478	11.3
May 15	May 24	1,200	1,952	1.62	49	1.2	58	....	43	.0	176	.....	3.5	12	394	10.1
May 25	June 3	3,850	4,204	1.10	43	1.1	.....	17	46	.0	171	170	3.9	14	460	13.0
June 4	June 13	5,350	6,611	1.24	20	1.0	53	14	52	.0	161	168	.7	8.5	424	17.7
June 14	June 23	3,200	4,719	1.48	26	.10	56	14	56	.0	157	168	2.6	8.4	418	17.8
June 24	July 4	4,000	3,982	1.00	25	1.2	57	....	45	.0	178	131	3.5	8.8	406	18.6
July 5	July 14	4,400	4,676	1.06	22	.05	53	10	46	.0	159	143	3.7	8.3	383	19.8
July 15	July 24	3,600	3,147	.87	24	.48	47	13	38	.0	157	103	4.1	6.7	316	22.6
July 25	Aug. 3	2,000	3,458	1.73	15	Tr.	46	....	37	.0	183	101	3.4	6.0	323	19.1
Aug. 4	Aug. 13	2,700	3,013	1.12	22	.30	44	12	29	.0	.....	99	3.0	5.5	295	16.5
Aug. 14	Aug. 23	2,400	2,651	1.12	21	.28	44	14	.....	.0	136	95	.9	7.0	291	13.8
Aug. 24	Sept. 2	2,000	1,677	.84	18	.05	45	14	.....	.0	152	92	1.3	.....	293	11.1
Sept. 3	Sept. 12	1,700	1,376	.81	20	.03	45	12	31	.0	155	87	1.6	11	307	9.9
Sept. 13	Sept. 22	1,200	878	.73	27	.33	53	10	38	.0	171	105	1.8	13	337	8.5
Sept. 23	Oct. 2	1,075	791	.74	27	.26	53	12	36	.0	167	108	1.6	13	339	8.3
Oct. 4	Oct. 13	1,100	792	.72	26	1.0	53	11	43	[c]Tr.	171	110	1.5	17	349	8.6
Oct. 14	Oct. 21	1,000	668	.67	28	.28	56	9.8	45	[c]Tr.	180	120	1.3	16	389	7.6
Mean		1,909	2,032	1.04	37	.73	62	18	44	.0	202	135	2.2	13	426	.....
Per ct. of anhydrous residue		.....	.....	.....	9.0	[d].2	15.0	4.4	10.7	24.2	.....	32.8	.5	3.2	.....	.....

[a] Analyses October 4, 1906, to February 12, 1907, by W. M. Barr; February 13 to 22, 1907, by H. S. Spaulding; February 23 to September 12, 1907, by Walton Van Winkle; September 13 to October 21, 1907, by R. B. Dole, Chase Palmer, and W. D. Collins.

[b] Sampling station above the entrance of Kansas River; gaging station below that stream.

[c] Abnormal; computed as HCO_3 in the average.

[d] Fe_2O_3.

Mineral analyses of water from Missouri River near Ruegg, Mo.[a]

[Parts per million, unless otherwise stated.]

Date (1906–7). From—	To—	Turbidity.	Suspended matter.	Coefficient of fineness.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.	Mean gage height (feet).[b]
Sept. 27	Oct. 7	1,800	1,784	0.99	29	Tr.	41	12	31	0.0	134	82	.....	14	291	10.3
Oct. 8	Oct. 17	1,900	1,461	.77	29	0.20	54	13	38	.0	195	.....	2.0	12	363	7.6
Oct. 19	Oct. 28	930	972	1.04	46	.10	66	19	55	.0	232	134	1.3	18	445	6.6
Oct. 29	Nov. 7	1,150	1,210	1.05	23	.20	67	22	.....	.0	225	126	1.3	21	424	7.7
Nov. 8	Nov. 17	1,650	1,208	.73	21	.25	68	22	53	.0	.....	133	2.4	15	442	7.6
Nov. 18	Nov. 27	780	885	1.14	24	.20	69	19	42	.0	226	126	1.8	16	421	7.6
Nov. 29	Dec. 9	500	527	1.06	28	.5	56	29	31	.0	227	104	.9	16	383	7.7
Dec. 10	Dec. 20	425	464	1.09	29	.30	69	24	35	.0	245	103	2.2	18	429	7.3
Dec. 21	Dec. 31	300	327	1.09	27	.30	70	26	40	.0	288	114	2.6	.....	438	5.2
Jan. 1	Jan. 10	375	296	.79	25	.40	.....	24	36	.0	268	100	2.2	21	420	6.9
Jan. 11	Jan. 20	550	427	.78	31	.80	54	19	31	.0	188	92	3.2	14	342	10.6
Jan. 21	Jan. 30	1,400	1,566	1.12	.....	.....	31	11	28	.0	.....	.....	4.1	10	262	14.6
Jan. 31	Feb. 9	350	326	.93	49	1.4	40	14	21	.0	127	.....	3.0	8.4	274	8.1
Feb. 10	Feb. 19	400	426	1.09	22	.45	67	20	31	.0	.....	128	4.0	18	378	7.6
Feb. 20	Mar. 1	1,400	1,894	1.35	30	.45	58	16	35	.0	184	97	4.5	14	348	11.0
Mar. 2	Mar. 11	1,000	1,626	1.62	14	.22	48	15	32	.0	159	94	3.7	12	292	10.4
Mar. 12	Mar. 21	2,000	2,016	1.01	41	1.7	50	11	27	.0	164	88	4.1	11	319	12.9
Mar. 23	Apr. 2	1,970	2,435	1.24	27	.7	42	13	39	.0	.....	112	1.1	14	345	11.2
Apr. 3	Apr. 12	2,600	2,389	.92	56	1.8	50	14	34	.0	149	96	3.4	8.9	350	11.2
Apr. 13	Apr. 22	4,000	3,249	.81	46	1.0	51	15	45	.0	173	125	5.0	10	401	11.1
Apr. 23	May 3	3,200	3,070	.96	47	1.6	51	16	38	.0	151	146	2.0	9.3	413	11.7
May 4	May 13	2,300	2,320	1.01	48	1.6	46	15	28	.0	144	102	3.6	7.6	342	13.4
May 14	May 23	1,500	2,270	1.52	33	1.2	39	10	18	.0	130	68	4.1	6.7	271	14.1
May 24	June 4	2,800	2,369	.84	17	.20	.....	14	36	.0	185	98	3.0	11	317	10.4
June 5	June 15	4,800	6,332	1.33	28	.20	52	15	39	.0	160	142	6.6	9.2	385	15.9
June 16	June 25	4,250	1,251	.29	16	.10	55	8.4	44	.0	151	135	2.7	6.9	354	15.6
June 26	July 5	3,600	4,002	1.11	18	.40	54	8.6	36	.0	149	95	5.0	6.3	306	17.4
July 6	July 16	3,600	3,937	1.10	23	.....	45	.....	37	.0	159	.....	1.9	7.0	333	15.8
July 17	July 26	4,000	4,429	1.12	16	.25	49	12	.....	.0	176	77	5.5	5.5	315	18.6
July 27	Aug. 6	3,300	2,460	.74	18	.19	43	.....	38	.0	144	87	2.7	6.0	282	16.0
Aug. 7	Aug. 17	3,900	3,346	.86	20	.10	40	12	40	.0	141	90	2.7	7.3	285	13.2
Aug. 18	Aug. 27	2,600	2,500	.96	17	.01	39	12	31	.0	141	80	2.2	7.3	254	11.5
Aug. 28	Sept. 6	1,000	1,321	1.32	19	.14	46	14	32	.0	153	85	1.1	10	277	9.1
Sept. 7	Sept. 16	1,280	1,050	.82	28	.06	46	12	38	[c] 4.8	156	84	1.3	14	300	8.0
Sept. 17	Sept. 26	1,000	994	.99	28	.19	50	14	38	[c] 4.8	167	88	1.5	14	319	7.0
Sept. 27	Oct. 6	900	889	.99	36	.06	53	14	37	[c] 9.6	173	95	1.4	17	351	6.8
Mean		1,931	1,890	1.02	29	.51	52	16	36	.0	178	104	2.9	12	346	.....
Per ct. of anhydrous residue		.....	.....	.....	8.5	[d] .2	15.3	4.7	10.6	25	.....	30.6	.8	3.5	.....	.....

[a] Analyses September 27, 1906, to February 19, 1907, by W. M. Barr; February 20 to March 1, 1907, by H. S. Spaulding; March 2 to September 6, 1907, by Walton Van Winkle; September 7 to September 16, 1907, by R. B. Dole, Chase Palmer, and W. D. Collins.

[b] Gaging station at Hermann, Mo., 70 miles above.

[c] Abnormal; computed as HCO_3 in the average.

[d] Fe_2O_3.

Mineral analyses of water from Monongahela River at Elizabeth, Pa.[a]

[Parts per million, unless otherwise stated.]

Date (1906–7). From—	To—	Turbidity.	Suspended matter.	Coefficient of fineness.	Total iron (Fe).	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.	Mean gage height (feet).[b]
Aug. 25	Sept. 3	42	50	1.19	2.7	13	1.0	12	2.2	9.6	0.0	23	34	0.7	2.8	94	8.60
Sept. 4	Sept. 13	34	26	.76	2.0	7.4	.5	15	2.4	9.4	.0	22	45	.6	3.5	97	7.02
Sept. 14	Sept. 23	9	16	1.78	.1	7.2	Tr.	16	4.0	11	.0	8.7	61	1.2	4.7	118	7.36
Sept. 24	Oct. 3	10	9	.90	1.1	6.2	.4	16	4.2	12	.0	4.8	64	.6	4.8	121	7.75
Oct. 4	Oct. 13	18	25	1.39	3.1	4.8	1.1	12	2.8	6.2	.0	16	40	.5	3.8	94	8.13
Oct. 14	Oct. 23	29	25	.86	3.4	9.6	.9	12	2.0	6.3	.0	17	32	1.5	3.4	83	9.06
Oct. 24	Nov. 2	31	34	1.10	2.3	7.4	.9	10	3.0	6.3	.0	21	28	1.2	3.0	74	7.91
Nov. 3	Nov. 12	42	27	.64	3.3	5.4	.7	13	2.6	7.2	.0	12	40	1.8	3.4	82	7.06
Nov. 13	Nov. 22	85	94	1.10	6.3	5.2	.4	15	2.8	7.9	.0	9.8	42	1.6	4.1	90	7.46
Nov. 23	Dec. 2	75	54	.72	3.0	7.6	.8	10	1.4	5.8	.0	20	21	2.6	2.6	66	8.37
Dec. 3	Dec. 12	60	81	1.35	3.7	5.6	.5	10	3.6	6.0	.0	15	28	1.0	3.5	69	11.02
Dec. 13	Dec. 21	.....	183	.....	5.6	6.2	.56	8.6	2.4	4.6	.0	15	19	1.5	1.9	56	14.56
Dec. 22	Jan. 2	47	54	1.15	2.5	5.6	.25	10	3.0	5.4	.0	15	27	1.5	2.9	63	12.40
Jan. 3	Jan. 12	80	93	1.16	3.5	4.4	.5	9.8	3.0	4.6	.0	15	24	1.5	2.4	64	13.25
Jan. 13	Jan. 22	350	362	1.03	17	8.2	.7	8.0	.....	4.9	.0	22	18	2.5	3.4	77	24.96
Jan. 23	Feb. 1	21	24	1.14	1.8	6.0	.07	12	3.6	6.5	.0	9.8	44	1.7	2.4	80	9.14
Feb. 2	Feb. 11	110	106	.96	6.1	5.4	.19	11	.6	5.5	.0	12	32	2.5	1.7	64	12.44
Feb. 12	Feb. 21	27	39	1.45	2.8	5.8	.12	13	2.0	6.5	.0	17	37	2.1	2.9	73	10.18
Feb. 22	Mar. 3	28	35	1.25	2.3	5.6	.25	10	1.4	5.5	.0	15	32	2.1	2.9	66	10.42
Mar. 4	Mar. 13	190	123	.65	4.4	6.0	.26	9.6	.4	5.2	.0	18	22	1.9	1.7	54	13.12
Mar. 14	Mar. 24	350	362	1.03	7.5	18	1.0	11	.6	8.5	.0	19	26	2.0	2.9	83	20.00
Mar. 25	Apr. 3	50	47	.94	2.5	5.4	.1	14	3.2	6.6	.0	16	44	Tr.	2.6	85	8.22
Apr. 4	Apr. 13	12	28	2.33	1.6	7.8	.06	18	3.0	12	.0	11	65	2.5	4.2	119	7.28
Apr. 14	Apr. 23	45	61	1.36	2.8	8.8	.46	11	1.8	6.3	.0	16	33	2.8	3.5	78	10.04
Apr. 24	May 3	65	83	1.28	2.6	8.8	.9	8.8	1.0	5.5	.0	18	20	3.0	2.9	63	11.15
May 4	May 13	45	66	1.47	2.1	17	.46	11	1.0	6.8	.0	23	25	1.8	3.0	80	10.82
May 14	May 23	37	49	1.32	2.5	18	.33	11	1.0	9.6	.0	23	27	1.5	3.4	81	9.43
May 24	June 2	40	52	1.30	2.1	12	.95	13	1.2	9.4	.0	22	32	1.8	2.9	87	8.05
June 3	June 12	45	61	1.36	1.9	7.4	.21	11	.8	7.2	.0	22	26	1.5	3.9	70	11.19
June 13	June 22	180	140	.78	4.0	11	.28	17	1.8	8.5	.0	50	24	3.0	3.6	96	11.50
June 23	July 3	38	36	.95	2.3	2.2	.05	14	2.4	5.2	.0	20	37	Tr.	3.6	79	7.50
July 4	July 13	70	66	.93	3.2	11	.28	12	2.0	8.5	.0	21	34	2.7	3.8	90	9.14
July 14	July 23	285	280	.98	13	14	1.4	8.2	1.0	6.6	.0	21	15	2.8	2.2	76	14.53
July 24	Aug. 1	205	158	.77	5.3	9.8	.46	11	1.8	.....	.0	.....	22	2.5	2.6	72	11.23
Aug. 3	Aug. 12	39	40	1.02	2.6	10	.28	13	2.8	7.7	.0	17	37	2.0	3.4	85	7.90
Aug. 13	Aug. 22	70	76	1.08	1.9	7.0	.35	13	2.8	9.3	.0	13	38	3.5	4.8	86	6.85
Aug. 23	Sept. 2	90	41	.45	3.5	8.4	.6	12	2.2	.....	.0	32	28	1.0	4.6	82	9.40
Mean		82	84	1.11	3.7	8.4	.49	12	2.2	7.3	.0	18	33	1.8	3.2	81	.....
Per ct. of anhydrous residue		.....	.....	.....	.....	10.8	c.9	15.5	2.8	9.4	11.5	.....	42.6	2.3	4.2	.....	.....

[a] Analyses August 25 to October 23, 1906, and from November 3 to December 2, 1906, by R. B. Dole; October 24 to November 2, 1906, and from December 3, 1906, to April 3, 1907, by R. B. Dole and M. G. Roberts; April 4 to September 2, 1907, by Chase Palmer and M. G. Roberts.

[b] Gaging station at Lock No. 4, 10 miles above.

[c] Fe_2O_3.

Mineral analyses of water from Muskingum River at Zanesville, Ohio.[a]

[Parts per million, unless otherwise stated.]

Date (1906–7).		Turbidity.	Suspended matter.	Coefficient of fineness.	Total iron (Fe).	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.	Mean gage height (feet).
From—	To—																
Sept. 3	Sept. 13	130	78	0.60	3.5	15	0.10	47	10	27	0.0	136	40	0.2	60	281	8.1
Sept. 14	Sept. 23	100	26	.26	2.9	23	.30	55	12	27	.0	155	41	.9	71	314	7.8
Sept. 24	Oct. 3	70	53	.76	2.2	32	Tr.	58	13	36	.0	154	52	.0	.....	356	8.1
Oct. 4	Oct. 13	85	62	.73	2.9	15	Tr.	55	11	46	.0	.....	53	2.1	.....	339	9.0
Oct. 14	Oct. 23	48	41	.85	2.6	13	Tr.	52	12	.....	.0	132	51	1.9	65	334	8.8
Oct. 24	Nov. 2	45	45	1.00	1.4	27	.06	53	11	33	5.3	136	50	1.0	62	305	8.6
Nov. 3	Nov. 13	24	17	.71	0.7	14	.03	60	13	36	Tr.	160	49	1.0	77	326	8.2
Nov. 14	Nov. 24	80	58	.74	1.8	12	.06	55	11	33	Tr.	168	50	1.1	.....	301	10.2
Nov. 25	Dec. 4	32	30	.94	1.4	11	.16	41	9.8	19	Tr.	111	43	3.0	38	216	9.5
Dec. 5	Dec. 15	150	111	.72	5.6	15	.23	37	8.4	20	3.6	96	40	4.5	.....	207	11.3
Dec. 16	Dec. 27	.....	95	.....	3.9	10	.19	35	8.4	14	.0	92	38	3.6	29	182	11.4
Dec. 28	Jan. 4	.....	87	.....	7.2	7.6	.14	32	6.0	12	.0	86	.....	3.8	28	169	13.6
Jan. 10	Jan. 20	.....	121	.....	11	13	.75	22	3.6	7.1	.0	61	.....	4.2	13	128	18.6
Jan. 21	Mar. 4	85	71	.84	3.2	11	.19	37	7.6	12	4.8	89	.....	3.7	29	192	11.7
Mar. 9	Mar. 31	480	56	12	.....	18	.20	28	.....	14	17	36	35	2.1	19	160	17.0
Apr. 6	Apr. 20	17	31	1.82	1.7	9.0	.11	44	9.8	22	.0	117	45	1.5	36	225	10.3
Apr. 21	Apr. 30	215	152	.71	5.8	25	.25	36	7.0	19	.0	93	39	1.6	29	207	13.5
May 1	May 10	42	40	.95	1.8	15	.23	38	8.4	17	.0	102	40	1.5	28	197	11.1
May 11	June 1	81	129	1.59	2.3	16	.09	26	8.8	21	.0	76	42	.0	36	187	11.3
June 2	June 18	105	94	.90	4.0	12	.18	26	7.6	17	.....	.....	35	1.5	24	181	11.8
June 19	July 4	3	52	17.33	1.0	.....	.5	30	9.6	24	2.4	70	42	.0	46	188	8.9
July 5	July 20	110	100	.91	4.0	12	.18	42	9.2	19	.0	127	38	1.2	38	227	9.5
July 21	July 31	260	225	.87	7.7	10	.4	28	5.8	14	.0	83	26	.8	20	150	12.6
Aug. 2	Aug. 11	62	28	.45	1.1	11	.10	46	9.0	21	.0	130	36	.8	37	223	8.8
Aug. 12	Aug. 21	2	11	5.50	0.3	11	.06	58	12	31	Tr.	160	45	.4	65	296	8.0
Aug. 22	Aug. 31	48	43	.90	1.4	7.6	.13	58	12	38	Tr.	145	50	.5	.....	328	8.1
Sept. 1	Sept. 10	35	30	.86	1.0	11	.16	64	12	.....	Tr.	156	51	.4	.....	373	7.8
Mean		96	70	1.71	3.2	14	.18	43	9.5	23	1.3	115	43	1.6	40	244	.....
Per ct. of anhydrous residue.		.....	.....	.....	.....	6.0	[b].1	18.5	4.1	9.9	25.0	.....	18.5	0.7	17.2	.....	.....

[a] Analyses September 3 to October 23, 1906, by R. B. Dole; October 21 to March 31, 1907, by R. B. Dole and M. G. Roberts; April 6 to September 10, 1907, by Chase Palmer and M. G. Roberts.

[b] Fe_2O_3.

Mineral analyses of water from Neuse River at Raleigh, N. C.[a]

[Parts per million, unless otherwise stated.]

Date (1906–7). From—	Date (1906–7). To—	Turbidity.	Suspended matter.	Coefficient of fineness.	Total iron (Fe).	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.
Oct. 1	Oct. 10	14	13	0.93	0.9	25	0.4	5.2	1.8	7.1	0.0	.....	2.6	0.0	3.8	68
Oct. 11	Oct. 20	14	11	.78	.5	27	.4	5.6	1.2	7.2	.0	39	1.0	Tr.	3.8	66
Oct. 21	Oct. 30	24	18	.75	.8	25	.4	6.0	1.2	7.9	.0	44	1.2	.0	4.6	68
Nov. 1	Nov. 10	10	5.8	.58	.8	20	.4	7.2	1.8	8.2	.0	39	3.0	.2	5.0	69
Nov. 11	Nov. 20	11	7.6	.69	.9	21	.3	5.4	1.6	7.7	.0	37	2.8	.2	4.6	63
Nov. 21	Nov. 30	9	5.8	.64	.5	21	.3	6.0	2.0	8.2	.0	40	2.8	Tr.	5.2	65
Dec. 1	Dec. 10	11	3.8	.34	.4	22	.3	5.6	1.8	8.0	.0	41	2.8	.0	4.8	65
Dec. 11	Dec. 20	26	16	.61	1.4	22	.65	6.4	1.6	8.0	.0	37	2.1	Tr.	5.8	68
Dec. 21	Dec. 30	45	29	.64	2.1	22	1.8	6.0	2.4	6.5	.0	32	2.3	Tr.	6.5	74
Dec. 31	Jan. 9	17	9.0	.53	1.3	21	.9	5.6	1.6	6.8	.0	35	1.8	Tr.	6.5	68
Jan. 10	Jan. 19	11	6.8	.62	1.0	22	.8	6.8	2.8	7.9	.0	39	3.5	Tr.	5.9	66
Jan. 20	Jan. 29	8	3.4	.42	.9	21	.6	6.4	2.6	7.8	.0	40	2.8	Tr.	5.9	65
Jan. 30	Feb. 8	15	10	.67	1.3	20	.8	6.2	2.6	6.3	.0	37	2.8	Tr.	.....	67
Feb. 9	Feb. 18	29	18	.62	1.5	22	1.4	5.8	1.8	6.0	.0	36	3.1	Tr.	.....	72
Feb. 19	Feb. 28	.....	72	.....	3.9	22	1.7	5.6	1.4	6.0	.0	23	4.9	.7	4.7	79
Mar. 1	Mar. 10	33	12	.36	2.1	22	2.0	5.0	1.2	7.6	.0	25	3.3	.5	4.1	76
Mar. 12	Mar. 21	.....	77	.....	2.8	26	2.6	4.8	1.2	6.9	.0	23	4.6	.6	3.5	85
Mar. 22	Mar. 31	18	20	1.11	1.0	22	.6	6.0	1.8	6.8	[b]2.4	28	2.0	.0	3.8	63
Apr. 1	Apr. 10	48	45	.94	1.8	16	1.3	5.8	1.6	8.2	.0	33	4.1	.5	5.0	62
Apr. 11	Apr. 21	27	19	.70	1.3	39	1.2	6.8	1.8	8.8	.0	40	3.6	.5	5.4	93
Apr. 22	May 2	81	73	.90	2.7	23	2.0	6.4	1.7	8.8	.0	32	4.8	1.0	4.2	77
May 3	May 12	82	67	.82	2.4	28	2.1	6.0	1.4	9.3	.0	32	3.5	.7	4.6	82
May 13	May 22	28	39	1.40	1.3	30	.95	6.2	1.8	11	[b]4.8	29	2.8	Tr.	4.2	78
May 23	June 1	53	57	1.08	1.8	22	.9	6.4	1.8	.....	.0	35	3.3	.9	3.8	66
June 3	June 12	100	96	.96	1.8	32	1.7	5.4	.8	10	.0	34	4.4	.0	3.6	90
June 13	June 22	325	247	.76	7.4	24	2.0	5.6	.8	8.2	.0	28	4.3	1.2	3.0	79
June 23	July 2	325	280	.86	13	39	3.7	8.2	2.0	12	.0	50	3.6	Tr.	4.6	.....
July 3	July 12	48	50	1.04	1.6	24	.9	6.6	.....	9.1	.0	37	3.5	.0	3.6	71
July 13	July 23	160	333	2.08	1.9	24	1.8	4.8	.....	8.5	.0	35	3.3	Tr.	3.0	74
July 24	Aug. 1	120	82	.68	1.6	24	1.5	6.4	3.0	6.3	.0	37	3.9	.8	3.2	75
Aug. 3	Aug. 12	540	428	.79	7.0	43	5.2	3.8	1.9	5.4	.0	18	7.6	.6	3.8	.....
Aug. 13	Aug. 22	70	26	.37	2.6	32	2.2	5.8	.....	5.7	.0	30	3.8	.5	3.2	89
Aug. 23	Sept. 1	40	37	.92	2.6	26	.66	6.8	.....	.....	.0	38	4.6	.6	4.2	75
Sept. 2	Sept. 11	170	113	.66	14	33	3.1	4.8	.....	7.6	.0	32	3.3	.6	.....	.....
Sept. 12	Sept. 21	30	28	.93	3.5	28	.8	6.4	3.4	9.4	.0	44	3.6	.5	4.2	81
Sept. 22	Oct. 1	120	76	.63	7.0	29	2.0	5.4	2.4	7.9	.0	34	3.9	.5	3.8	84
Mean		78	68	.79	2.8	26	1.4	5.9	1.8	7.9	.0	35	3.4	.3	4.4	73
Per ct. of anhydrous residue		.....	.....	.....	.....	37.7	[c]2.9	8.6	2.6	11.5	25.0	.....	4.9	.4	6.4	.....

[a] Analyses October 1 to December 10, 1906, by R. B. Dole; December 11, 1906, to March 31, 1907, by R. B. Dole and M. G. Roberts; April 1 to July 2, 1907, by Chase Palmer and M. G. Roberts; July 3 to October 1, 1907, by R. B. Dole, Chase Palmer, and W. D. Collins.

[b] Abnormal; computed as HCO_3 in the average.

[c] Fe_2O_3.

Mineral analyses of water from North Platte River near North Platte, Nebr.[a]

[Parts per million, unless otherwise stated.]

Date (1906–7).		Turbidity.	Suspended matter.	Coefficient of fineness.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.	Mean gage height (feet).
From—	To—															
Sept. 10	Sept. 19	120	91	0.16	.....	0.10	..7	8.5	28	0.0	161	54	Tr.	5.0	262	1.9
Sept. 20	Oct. 1	110	117	1.06	63	1.1	50	17	36	.0	167	114	1.8	6.7	285	2.0
Oct. 2	Oct. 14	90	68	.75	50	.10	40	11	29	.0	168	63	.4	6.1	277	1.9
Oct. 15	Oct. 24	85	71	.84	42	.15	46	11	31	.0	155	72	Tr.	7.9	289	2.0
Oct. 25	Nov. 3	290	275	.95	50	.15	41	11	27	.0	155	62	1.0	5.7	264	2.4
Nov. 4	Nov. 13	240	154	.64	25	.30	40	11	.....	.0	169	69	1.3	9.2	292	2.4
Nov. 14	Nov. 23	150	129	.86	43	.40	50	12	35	.0	189	91	.4	9.0	327	2.1
Nov. 24	Dec. 3	130	116	.89	44	.20	46	11	35	.0	168	78	.4	6.7	300	2.2
Dec. 4	Dec. 13	160	118	.74	48	.35	50	16	37	.0	179	.....	1.3	8.0	333	....
Dec. 14	Dec. 23	140	115	.82	52	.15	51	15	39	.0	205	102	Tr.	9.2	372	....
Dec. 24	Jan. 2	150	122	.81	43	1.2	47	14	37	.0	178	88	Tr.	8.1	306	....
Jan. 3	Jan. 12	20	12	.60	35	Tr.	52	14	37	.0	198	97	.4	9.5	326	....
Jan. 13	Jan. 22	20	14	.70	36	.05	56	15	41	.0	212	102	.2	9.4	359	....
Jan. 23	Feb. 1	150	117	.78	37	.12	54	14	39	.0	187	84	.0	11	351	....
Feb. 3	Feb. 12	150	138	.92	30	.12	46	9.5	31	.0	162	76	.7	7.3	272	....
Feb. 13	Feb. 22	300	330	1.10	34	.10	52	12	.....	.0	146	41	2.8	6.7	270	....
Feb. 23	Mar. 4	210	148	.70	45	.15	47	12	34	.0	170	82	1.6	7.0	309	....
Mar. 5	Mar. 15	240	148	.62	31	.08	52	14	36	.0	167	.....	.9	10	331	....
Mar. 16	Mar. 25	165	119	.72	30	Tr.	47	13	34	.0	186	86	.4	9.0	319	....
Mar. 26	Apr. 4	1,840	1,715	.93	56	.05	52	11	30	.0	146	112	.8	4.0	331	....
Apr. 5	Apr. 14	800	585	.73	52	.10	43	11	26	.0	145	77	1.8	6.7	314	2.5
Apr. 15	Apr. 24	675	436	.64	43	.30	44	12	28	.0	145	84	.7	7.3	285	2.4
Apr. 25	May 4	440	426	.97	41	.55	38	.....	24	.0	135	67	.5	4.8	258	2.5
May 5	May 14	165	187	1.13	38	.20	39	11	23	.0	144	68	1.1	5.5	264	2.3
May 15	May 24	370	608	1.64	40	.22	42	10	31	.0	156	63	1.9	4.5	272	2.4
May 25	June 3	680	1,036	1.52	35	.40	41	7.9	26	.0	146	59	1.8	5.3	260	3.2
June 4	June 13	350	697	2.00	34	.48	38	9.4	21	.0	137	58	5.0	4.7	246	3.4
June 14	June 23	375	534	1.42	26	.18	43	6.2	32	.0	148	56	6.2	4.4	249	3.3
June 24	June 30	290	381	1.32	13	.05	39	5.1	26	.0	156	54	1.3	2.5	219	3.5
Mean		307	311	.95	40	.26	46	12	32	.0	165	76	1.2	6.9	295	....
Per ct. of anhydrous residue		.....	.....	.....	13.5	[b].1	15.6	4.1	10.8	27.5	.....	25.7	.4	2.3	.....	....

[a] Analyses September 10, 1906, to February 12, 1907, by W. M. Barr; February 13 to 22, 1907, by H. S. Spaulding; February 24 to June 30, 1907, by Walton Van Winkle.

[b] Fe_2O_3.

Mineral analyses of water from Oconee River near Dublin, Ga.[a]

[Parts per million, unless otherwise stated.]

Date (1906–7).		Turbidity.	Suspended matter.	Coefficient of fineness.	Total iron (Fe).	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.	Mean gage height (feet).
From—	To—																
Oct. 18	Oct. 27	55	23	0.42	.....	29	0.6	9.0	1.2	.....	0.0	33	.....	0.4	4.0	76	1.4
Oct. 28	Nov. 6	75	51	.68	.....	32	2.0	11	.8	.....	.0	39	.....	.4	4.0	83	.6
Nov. 7	Nov. 17	85	28	.33	.....	31	.9	8.8	1.2	.....	.0	32	.....	.7	2.0	68	.8
Nov. 18	Nov. 27	85	65	.76	.....	24	.40	8.8	1.2	.....	.0	32	.....	.1	4.0	70	1.9
Nov. 28	Dec. 7	80	52	.65	.....	26	.5	9.6	1.6	.....	.0	34	.....	.7	4.5	78	.9
Dec. 8	Dec. 17	155	94	.61	.....	31	.7	12	.....	.....	.0	49	.....	.9	4.8	89	1.7
Dec. 19	Jan. 3	160	125	.78	.....	28	1.2	8.3	.8	.....	.0	27	.....	.8	5.0	83	3.1
Jan. 4	Jan. 15	105	85	.81	.....	20	.5	5.7	Tr.	.....	.0	20	.....	.4	4.0	61	3.4
Jan. 16	Jan. 26	38	32	.84	.....	30	.9	14	4.4	.....	.0	51	.....	1.1	4.2	94	1.4
Jan. 27	Feb. 6	80	59	.74	.....	26	.8	12	.....	.....	.0	56	.....	1.2	3.0	85	4.3
Feb. 7	Feb. 18	40	36	.90	.....	22	1.0	5.6	1.2	.....	.0	20	.....	.5	5.0	60	7.5
Mar. 2	Mar. 11	240	204	.85	.....	34	1.1	7.6	Tr.	.....	.0	27	.....	.6	2.5	69	6.9
Mar. 12	Mar. 21	110	100	.91	.....	16	.6	9.6	1.2	.....	.0	32	.....	.4	2.0	50	3.2
Mar. 22	Mar. 31	35	28	.80	.....	24	1.6	12	1.6	.....	.0	41	.....	.3	4.0	73	1.6
Apr. 1	Apr. 10	75	65	.87	.....	20	1.3	9.6	1.6	.....	.0	32	.....	.2	6.5	64	1.6
Apr. 11	Apr. 24	185	176	.95	.....	20	2.4	10	2.4	.....	.0	34	.....	.4	5.0	66	3.3
Apr. 25	May 4	95	75	.79	.....	16	1.8	7.0	1.6	.....	.0	24	.....	.3	2.5	48	5.4
May 5	May 14	200	206	1.03	.....	18	2.5	10	1.6	.....	.0	34	.....	.2	4.5	61	4.0
May 15	May 24	100	69	.69	6.1	18	.42	7.8	2.2	8.4	.0	44	5.4	4.0	2.2	70	1.9
May 25	June 3	350	232	.66	15	21	Tr.	7.7	2.0	11	.0	43	6.2	1.5	2.6	68	1.4
June 4	June 13	375	220	.59	16	22	Tr.	6.6	2.2	7.9	.0	45	5.6	1.0	1.9	69	.9
June 14	June 23	400	275	.69	16	11	Tr.	6.3	2.1	8.1	.0	38	6.0	Tr.	1.4	51	1.0
June 24	July 3	230	266	1.16	12	10	Tr.	6.6	3.2	8.3	.0	34	8.1	.6	1.8	54	2.4
July 4	July 14	350	354	1.01	15	15	Tr.	6.6	1.6	9.4	.0	37	4.9	3.2	2.4	57	1.6
July 15	July 24	400	233	.58	9.6	13	Tr.	7.1	1.9	6.2	[b]4.8	27	7.5	.6	3.1	62	.8
July 25	Aug. 2	650	504	.77	28	17	Tr.	6.3	1.9	8.1	.0	34	6.3	2.3	3.4	62	2.7
Aug. 4	Aug. 13	400	266	.66	19	14	.02	5.9	1.2	7.9	.0	32	6.1	2.0	2.9	55	.9
Aug. 15	Aug. 24	425	460	1.08	34	21	Tr.	7.2	.9	10	.0	40	5.4	4.2	3.1	74	2.0
Aug. 26	Sept. 7	290	205	.71	16	18	Tr.	6.9	1.1	7.9	.0	40	5.0	.7	2.4	62	.7
Sept. 8	Sept. 17	400	328	.82	24	18	Tr.	6.4	1.1	12	.0	41	5.5	1.0	2.6	63	1.0
Sept. 28	Oct. 7	350	379	1.08	15	16	.02	11	1.7	8.3	.0	54	7.4	1.7	4.9	84	3.9
Oct. 8	Oct. 17	40	.....	.....	3.5	15	.6	8.5	1.9	9.2	.0	50	7.5	Tr.	2.8	.....	.4
Mean		208	171	.78	.....	21	.68	8.5	1.6	8.8	.0	37	6.2	1.0	3.4	68	.....
Per ct. of anhydrous residue		.....	.....	.....	.....	30.2	[c]1.4	12.2	2.3	12.6	26.1	.....	8.9	1.4	4.9	.....	.....

[a] Analyses October 18, 1906, to May 14, 1907, by J. R. Evans; May 15 to October 17, 1907, by R. B. Dole, Chase Palmer, and W. D. Collins.

[b] Abnormal; computed as HCO in the average.

[c] Fe_2O_3.

Mineral analyses of water from Ocmulgee River near Macon, Ga.[a]

[Parts per million, unless otherwise stated.]

Date (1906–7).		Turbidity.	Suspended matter.	Coefficient of fineness.	Total iron (Fe).	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.	Mean gage height (feet).
From—	To—																
Oct. 19	Oct. 28	35	27	0.77	.....	12	0.6	5.6	1.6	.....	0.0	20	.....	0.1	4.0	50	3.7
Oct. 29	Nov. 7	49	14	.29	.....	32	.5	5.2	.8	.....	.0	22	.....	.5	3.0	66	2.9
Nov. 8	Nov. 17	50	18	.36	.....	30	.20	8.3	Tr.	.....	.0	27	.....	.5	1.5	77	3.0
Nov. 18	Nov. 27	65	26	.40	.....	30	.30	7.5	1.2	.....	.0	22	.....	.2	1.8	72	4.0
Nov. 28	Dec. 7	60	24	.40	.....	26	.9	8.1	1.6	.....	.0	25	.....	.6	1.5	77	2.8
Dec. 8	Dec. 17	75	46	.61	.....	29	.7	9.6	1.2	.....	.0	32	.....	.8	1.7	75	3.3
Dec. 21	Jan. 4	30	20	.67	.....	26	.9	4.4	Tr.	.....	.0	15	.....	.1	4.0	56	5.4
Jan. 5	Jan. 16	60	42	.70	.....	18	.8	5.6	Tr.	.....	.0	12	.....	.5	3.5	88	4.3
Jan. 17	Jan. 26	40	28	.70	.....	21	.8	3.6	Tr.	.....	.0	12	.....	.4	2.0	46	3.3
Jan. 27	Feb. 5	240	189	.79	.....	34	1.8	4.6	2.4	.....	.0	.....	.....	.5	2.5	64	7.2
Feb. 6	Feb. 15	75	60	.80	.....	32	.8	7.6	Tr.	.....	.0	24	.....	.4	2.0	58	7.8
Feb. 16	Feb. 25	40	33	.83	.....	33	.7	8.0	1.6	.....	.0	27	.....	.3	1.5	57	4.0
Feb. 26	Mar. 7	210	178	.85	.....	38	1.4	6.8	Tr.	.....	.0	22	.....	1.2	3.5	71	8.9
Mar. 8	Mar. 17	55	46	.84	.....	15	.8	6.0	0.8	.....	.0	20	.....	.6	3.0	47	5.0
Mar. 18	Mar. 27	35	27	.77	.....	14	1.0	9.6	Tr.	.....	.0	29	.....	.5	3.5	52	3.4
Mar. 28	Apr. 6	25	23	.92	.....	27	1.2	11	Tr.	.....	.0	34	.....	.7	3.5	70	3.1
Apr. 7	Apr. 16	30	29	.97	.....	23	2.1	9.2	Tr.	.....	.0	29	.....	.8	4.0	64	3.4
Apr. 17	Apr. 26	560	511	.91	.....	21	1.7	5.5	1.2	.....	.0	24	.....	1.6	2.5	48	7.7
Apr. 27	May 6	450	416	.92	.....	24	1.4	4.5	.8	.....	.0	15	.....	1.8	3.0	50	5.3
May 7	May 16	204	158	.77	.....	31	1.1	6.7	.....	10	.0	40	3.3	1.0	5.0	96	4.5
May 17	May 26	45	31	.69	.....	25	2.0	5.7	2.9	8.1	.0	43	2.0	.3	4.0	85	3.0
May 27	June 5	310	234	.75	.....	26	1.2	4.9	2.8	11	.0	.....	5.9	.4	2.5	91	3.1
June 6	June 15	226	179	.79	.....	23	1.2	5.7	2.6	4.4	.0	37	4.9	.4	3.0	78	2.8
June 16	June 26	410	241	.59	.....	25	2.4	4.1	2.4	6.9	.0	31	4.8	1.1	4.0	86	2.5
June 27	July 11	670	527	.79	.....	23	2.0	6.5	1.5	6.3	.0	31	5.2	.7	3.5	84	4.3
July 12	July 21	416	331	.79	.....	32	1.6	8.1	2.2	7.5	.0	41	6.8	1.0	4.0	94	2.2
Aug. 3	Aug. 12	1,100	807	.73	21	7.5	Tr.	5.0	1.5	6.8	.0	24	4.7	1.1	1.4	35	2.7
Aug. 13	Aug. 22	580	552	.95	35	21	Tr.	5.8	1.8	11	.0	40	4.3	1.2	1.8	64	3.3
Aug. 24	Sept. 9	550	414	.75	16	16	Tr.	5.8	1.8	6.6	.0	32	4.7	1.3	2.6	53	1.7
Sept. 10	Sept. 19	270	133	.49	10	41	Tr.	6.4	2.3	7.4	.0	38	5.8	.9	1.0	87	1.1
Sept. 20	Sept. 30	400	260	.65	8.9	29	Tr.	5.1	1.8	11	.0	34	6.4	1.0	2.3	70	3.7
Oct. 1	Oct. 10	180	90	.50	2.6	42	Tr.	5.7	1.8	11	.0	37	.....	.7	3.0	85	1.6
Oct. 12	Oct. 21	35	32	.91	1.1	28	Tr.	4.7	1.4	8.1	.0	30	5.5	.6	3.2	70	.9
Mean		230	174	.72	.....	26	.9	6.3	1.2	8.3	.0	28	4.9	.7	2.8	69	.....
Per ct. of anhydrous residue		.....	.....	.....	.....	39.8	[b]2.0	9.6	1.8	12.7	21.2	.....	7.5	1.1	4.3	.....	.....

[a] Analyses October 19, 1906, to May 6, 1907, by J. R. Evans; May 7 to July 21, 1907, by W. D. Collins; August 3 to October 21, by R. B. Dole, Chase Palmer, and W. D. Collins.

[b] Fe_2O_3.

Mineral analyses of water from Oostanaula River near Rome, Ga.[a]

[Parts per million, unless otherwise stated.]

Date (1906–7). From—	Date (1906–7). To—	Turbidity.	Suspended matter.	Coefficient of fineness.	Total iron (Fe).	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.	Mean gage height (feet).
Oct. 21	Oct. 30	25	18	0.72	....	9.6	Tr.	12	.....	.....	0.0	39	.....	0.1	2.0	63	6.1
Oct. 31	Nov. 9	40	14	.35	....	23	0.30	12	.....	.....	.0	46	.....	.6	3.0	81	2.8
Nov. 10	Nov. 19	140	120	.86	....	34	.40	9.9	.....	.....	.0	39	.....	.3	.....	79	3.3
Nov. 20	Dec. 1	125	96	.77	....	34	.6	11	1.2	.....	.0	37	.....	.4	1.5	85	14.4
Dec. 2	Dec. 11	95	69	.73	....	29	.40	9.6	.....	.....	.0	34	.....	.6	1.5	70	3.6
Dec. 12	Dec. 21	105	77	.73	....	27	.9	8.2	1.2	.....	.0	32	.....	.8	1.8	66	6.3
Dec. 22	Dec. 31	70	53	.76	....	25	.7	11	1.6	.....	.0	44	.....	.4	2.0	82	6.6
Jan. 1	Jan. 10	65	41	.63	....	22	.8	9.6	1.2	.....	.0	37	.....	.6	1.5	62	8.0
Jan. 11	Jan. 20	25	16	.64	....	14	.20	11	1.2	.....	.0	37	.....	1.0	1.8	67	3.0
Jan. 21	Jan. 31	30	21	.70	....	21	.8	13	1.2	.....	.0	44	.....	.2	1.5	75	3.2
Feb. 1	Feb. 10	40	28	.70	....	18	.6	11	3.2	.....	.0	41	.....	.7	2.0	66	9.0
Feb. 11	Feb. 20	4	3.6	.90	....	13	.7	11	0.8	.....	.0	37	.....	.3	2.0	54	3.6
Feb. 21	Mar. 4	165	124	.75	....	33	1.3	14	2.0	.....	.0	44	.....	.4	3.0	83	9.7
Mar. 5	Mar. 14	45	38	.84	....	16	.9	7.6	Tr.	.....	.0	24	.....	.4	2.0	47	6.1
Mar. 15	Mar. 24	25	23	.92	....	18	1.2	15	1.2	.....	.0	51	.....	.8	1.0	76	4.0
Mar. 25	Apr. 3	12	10	.83	....	19	1.2	11	.....	.....	.0	34	.....	.6	2.5	62	3.1
Apr. 4	Apr. 13	65	56	.86	....	17	1.4	14	3.2	.....	.0	.....	.....	.4	2.0	70	3.4
Apr. 14	Apr. 23	60	56	.93	....	8.8	1.4	15	4.0	.....	.0	59	.....	.2	2.0	68	3.6
Apr. 24	May 2	260	236	.91	....	7.8	1.6	13	.....	.....	.0	51	.....	.0	3.0	61	4.7
May 3	May 13	220	220	1.00	....	18	.7	15	3.3	8.8	.0	72	2.6	.8	1.0	100	4.2
May 14	May 23	150	149	1.00	....	18	1.0	11	3.1	11	.0	72	4.3	.0	1.5	92	5.4
May 24	June 5	340	318	.93	....	29	1.6	12	3.2	11	.0	71	4.3	.6	1.5	120	5.0
June 6	June 15	200	170	.85	....	25	.6	.....	3.3	6.0	.0	74	4.8	.0	2.5	99	3.8
June 16	June 26	180	114	.63	....	28	.40	14	4.1	8.2	.0	78	3.6	.6	2.0	101	2.4
June 27	July 7	415	378	.91	....	26	1.2	12	3.7	6.6	.0	68	3.8	.7	2.0	106	2.9
July 8	July 17	370	370	1.00	....	39	.8	13	3.9	12	.0	78	5.5	.4	2.0	122	2.4
Aug. 7	Aug. 16	260	234	.90	....	31	Tr.	9.6	4.6	13	.0	73	5.1	1.0	1.0	105	1.9
Aug. 17	Aug. 26	260	198	.76	....	23	Tr.	13	2.9	9.4	.0	67	4.8	1.0	0.6	87	2.0
Sept. 27	Oct. 6	125	87	.70	....	47	Tr.	7.3	3.2	7.6	.0	51	3.6	.5	1.7	109	2.6
Oct. 7	Oct. 17	45	37	.80	1.2	44	Tr.	14	5.0	7.9	.0	74	3.8	....	1.2	118	1.5
Oct. 18	Oct. 28	10	8.8	.88	Tr.	17	Tr.	11	2.9	9.1	.0	70	3.3	....	1.8	81	1.0
Mean		128	109	.80	....	24	.7	12	2.6	9.2	.0	53	4.1	.4	1.8	82	....
Per ct. of anhydrous residue		.....	.....	.....	.....	29.6	[b]1.2	14.8	3.2	11.3	32.2	..	5.0	.5	2.2	....	....

[a] Analyses October 21, 1906, to May 2, 1907, by Jas. R. Evans; May 2 to July 17, 1907, by W. D. Collins; August 7 to October 28, 1907, by R. B. Dole, Chase Palmer, and W. D. Collins.

[b] Fe_2O_3.

Mineral analyses of water from Oswegatchie River at Ogdensburg, N. Y.[a]

[Parts per million, unless otherwise stated.]

Date. (1906–7).		Turbidity.	Suspended matter.	Coefficient of fineness.	Total iron (Fe).	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.	Mean gage height (feet).
From—	To—																
Aug. 28	Sept. 10	8	8	1.00	1.2	12	0.4	11	2.9	.....	0.0	45	6.2	0.0	Tr.	80	4.6
Sept. 11	Sept. 20	9	9	1.00	.3	14	.28	11	3.2	.....	.0	45	4.8	.0	Tr.	82	4.8
Sept. 21	Sept. 30	7	6	.86	.5	13	.4	12	3.4	.....	.0	49	7.4	Tr.	Tr.	91	4.6
Oct. 1	Oct. 10	8	6	.75	5.2	13	Tr.	9.6	4.8	.....	.0	36	7.2	.0	Tr.	81	5.1
Oct. 11	Oct. 20	6	6.4	1.07	.2	13	Tr.	12	3.6	.....	.0	46	6.6	Tr.	Tr	83	6.0
Oct. 21	Oct. 30	8	14	1.75	.5	15	Tr.	14	4.0	6.9	.0	59	7.1	Tr.	Tr.	90	6.6
Oct. 31	Nov. 9	7	4.6	.66	.1	14	.10	15	3.8	6.5	.0	64	7.9	.0	Tr.	94	6.0
Nov. 10	Nov. 20	9	13	1.44	.5	16	.20	15	4.0	6.1	.0	59	13	.0	Tr.	100	5.5
Nov. 22	Nov. 30	10	9.0	.90	.6	11	.30	13	3.6	4.9	.0	56	8.6	.0	Tr.	83	6.3
Dec. 1	Dec. 11	6	9.4	1.57	.1	7.8	.10	15	3.4	5.8	.0	59	8.6	Tr.	Tr.	84	6.1
Dec. 12	Dec. 22	5	2.8	.56	.7	10	.18	13	4.4	4.9	.0	53	9.0	.9	.7	79	5.7
Dec. 23	Jan. 1	7	4.8	.68	.6	8.5	.21	15	4.8	3.5	.0	59	8.5	.6	.5	83	5.4
Jan. 2	Jan. 11	17	14	.82	.6	8.8	.21	13	4.0	3.3	.0	51	7.9	.6	.2	72	7.0
Jan. 12	Jan. 21	6	3.4	.57	.4	7.5	.16	14	4.2	3.6	.0	52	6.9	1.0	.6	78	6.5
Jan. 22	Feb. 1	7	4.2	.60	.3	8.0	.16	12	3.4	3.5	.0	51	7.7	.6	1.6	72	6.5
Feb. 2	Feb. 12	18	16	.89	.3	5.6	.10	13	2.0	4.1	[b]6.8	40	6.4	.0	Tr.	70	5.1
Feb. 13	Feb. 22	9	4.4	.49	.4	8.6	.18	12	2.8	4.9	.0	46	7.1	1.0	2.2	69	4.7
Feb. 23	Mar. 6	10	5.6	.56	.4	8.4	.14	12	2.8	3.9	.0	44	8.7	1.2	Tr.	70	4.6
Mar. 7	Mar. 18	7	3.2	.46	.3	9.2	.14	10	2.8	5.2	.0	37	9.4	1.9	Tr.	67	4.9
Mar. 19	Mar. 29	10	30	3.00	.8	3.0	.05	11	2.8	5.7	.....	.....	6.8	.0	Tr.	64	6.8
Apr. 10	Apr. 19	6	10	1.67	.5	12	.13	14	3.9	6.8	.0	59	7.1	1.9	1.9	78	6.3
Apr. 20	Apr. 30	9	17	1.89	.8	12	.15	14	4.1	6.3	.0	60	7.2	1.0	.2	80	5.5
May 1	May 10	23	27	1.18	1.4	.....	.30	14	3.7	6.4	.0	57	7.6	1.4	.6	87	6.8
May 11	May 20	8	21	2.62	.7	8.2	.10	14	3.8	7.5	[b]2.4	56	7.1	Tr.	1.0	75	6.3
May 21	May 30	3	8.5	2.83	.4	7.6	.13	13	3.6	6.1	.0	56	7.6	Tr.	.6	74	5.4
May 31	June 9	8	17	2.12	.5	7.2	.14	14	3.5	4.6	[b]4.1	53	7.1	.8	.2	73	5.3
June 11	June 20	3	18	6.00	.5	8.2	.12	14	3.9	4.6	.0	61	7.4	.8	.6	78	4.9
June 21	June 30	8	13	1.62	1.0	.....	.35	12	3.2	5.6	.0	64	9.1	.5	.2	88	4.8
July 1	July 10	15	13	.87	.8	6.4	.30	12	3.6	.....	.....	.....	10	Tr.	.6	69	4.9
July 11	July 20	10	17	1.70	.8	6.6	.21	12	2.7	6.3	.0	49	9.3	Tr.	Tr.	69	4.7
July 21	July 30	10	11	1.10	.8	5.4	.35	12	3.8	5.4	.0	.....	8.2	Tr.	Tr.	62	4.5
July 31	Aug. 10	5	5.6	1.12	.9	6.2	.44	11	3.3	4.7	.0	.....	9.4	.3	1.2	60	4.5
Aug. 11	Aug. 20	5	7.2	1.44	.9	7.6	.52	11	3.2	.....	.0	.....	10	.2	.6	65	4.4
Aug. 21	Aug. 30	7	7.2	1.03	.9	9.4	.56	10	3.4	.....	.0	.....	12	.2	1.2	75	4.4
Aug. 31	Sept. 9	3	4.6	1.53	.8	7.6	.35	10	3.5	6.3	.0	.....	13	.2	Tr.	70	4.5
Mean		8	10	1.38	.7	9.4	.21	13	3.5	5.3	.0	53	8.2	.4	.4	77	....
Per ct. of anhydrous residue		.....	.....	.....	.....	14.1	[c].4	19.5	5.3	8.0	39.2	.....	12.3	.6	.6	.....	.....

[a] Analyses August 28 to December 11, 1906, by R. B. Dole; December 12, 1906, to March 29, 1907, by R. B. Dole and M. G. Roberts; April 10 to June 30, 1907, by Chase Palmer and M. G. Roberts; July 1 to September 9, 1907, by R. B. Dole, Chase Palmer, and W. D. Collins.

[b] Abnormal; computed as HCO_3 in the average.

[c] Fe_2O_3.

Mineral analyses of water from Pearl River near Jackson, Miss.[a]

[Parts per million, unless otherwise stated.]

Date. (1906–7).		Turbidity.	Suspended matter.	Coefficient of fineness.	Total iron (Fe).	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.	Mean gage height (feet).
From—	To—																
Oct. 16	Oct. 26	45	28	0.62	.....	13	.....	5.2	0.8	.....	0.0	20	....	0.4	5.0	48	17.8
Oct. 27	Nov. 8	75	38	.51	.....	27	0.20	5.5	.8	.....	.0	22	....	.9	4.0	69	3.0
Nov. 9	Nov. 20	30	8.0	.67	.....	21	.7	9.6	1.2	.....	.0	32	.	.4	1.8	67	2.0
Nov. 21	Dec. 3	35	14	.40	.....	23	.8	10	1.6	.....	.0	34	...	.7	2.0	72	3.3
Dec. 4	Dec. 15	40	22	.55	.....	19	.7	12	1.2	.....	.0	41	....	.9	2.2	65	3.4
Dec. 26	Jan. 5	105	76	.72	.....	28	.30	6.5	Tr.	.....	.0	22	....	.5	6.0	62	7.8
Jan. 6	Jan. 15	55	47	.85	.....	32	.9	4.7	.4	.....	.0	20	....	1.0	4.2	77	9.6
Jan. 16	Jan. 26	25	18	.72	.....	19	.6	.	1.6	.....	.0	54	.....	.7	6.0	76	5.0
Jan. 28	Feb. 6	60	38	.63	.....	19	.5	4.4	1.2	.....	.0		..	.9	4.0	52	7.9
Feb. 7	Feb. 16	30	26	.87	.....	15	.40	4.4	1.2	.....	.0	15	...	.3	3.5	43	18.5
Feb. 17	Feb. 26	90	84	.93	.....	20	.10	4.4	Tr.	.....	.0		.....	.1	3.5	46	8.9
Mar. 1	Mar. 16	85	63	.74	.....	14	.20	4.4	Tr.	.....	.0	12	...	.2	4.0	36	23.0
Mar. 17	Mar. 26	60	40	.67	.....	13	.10	10	1.6	.....	.0	34	...	.5	1.8	50	9.5
Mar. 27	Apr. 5	30	26	.87	.....	20	.40	8.8	.8	.....	.0	29	....	.8	4.5	61	4.3
Apr. 6	Apr. 18	160	175	1.10	.....	16	.5	8.4	Tr.	....	.0	27	.....	.6	2.5	60	3.7
Apr. 19	Apr. 29	35	56	1.60	.....	31	2.8	4.0	...	.....	.0	.....	.....	.7	2.5	52	7.9
Apr. 30	May 9	170	147	.86	.....	23	1.7	5.0	Tr.	...	.0	17	.....	.9	3.0	46	12.4
May 10	May 23	60	47	.78	2.8	10	.05	5.1	1.2	7.9	.0	28	5.5	1.0	2.5	50	21.0
May 24	June 2	60	50	.83	6.6	11	.10	6.2	1.6	6.7	.0	28	6.7	1.1	2.6	45	12.7
June 3	June 13	45	38	.84	4.4	26	.07	7.9	1.4	8.3	.0	44	6.6	1.0	3.1	79	5.4
June 14	June 23	50	50	1.00	9.6	24	.04	8.1	1.6	11	0	44	7.4	1.2	3.4	73	3.6
June 24	July 3	50	50	1.00	11	20	Tr.	9.7	1.6	13	.0	56	6.2	.5	3.2	76	2.7
July 4	July 13	100	59	.59	7.0	13	.03	7.0	1.9	14	.0	30	11	...	5.5	75	3.4
July 14	July 23	45	36	.80	7.9	15	.03	8.6	1.7	9.6	.0	45	6.9	.9	3.2	65	2.6
July 24	Aug. 3	15	41	2.73	3.5	13	.03	9.7	1.6	8.8	.0	40	6.8	Tr.	2.9	54	1.9
Aug. 4	Aug. 14	30	15	.50	3.5	11	.03	8.3	1.7	7.6	.0	40	6.2	.7	2.6	52	1.9
Aug. 15	Aug. 24	45	37	.82	2.4	11	.04	7.7	1.4	8.3	.0	32	6.1	2.2	5.0	59	2.1
Aug. 25	Sept. 3	45	33	.73	5.2	12	.04	6.3	.9	7.9	.0	29	4.9	.8	2.6	53	2.5
Sept. 4	Sept. 14	40	37	.92	3.2	13	.04	7.4	1.0	9.2	.0	38	4.8	.0	2.6	56	1.9
Sept. 15	Sept. 26	50	32	.64	6.1	9.7	.03	6.9	1.5	4.7	.0	30	4.7	.7	2.4	41	1.5
Sept. 27	Oct. 7	10	16	1.60	2.8	14	.03	8.0	2.1	8.3	.0	41	6.0	Tr.	3.6	63	1.0
Oct. 8	Oct. 19	30	21	.70	2.3	8.9	.03	6.9	1.3	8.3	.0	37	5.6	.2	2.9	52	1.3
Mean		56	46	.93	.....	18	.37	7.1	1.1	8.9	.0	32	6.4	.7	3.4	59	....
Per ct. of anhydrous residue		.....	.....	.....	.....	29.1	[b].8	11.5	1.8	14.4	25.5	....	10.3	1.1	5.5	.....	.....

[a] Analyses October 16, 1906, to May 8, 1907, by Jas. R. Evans; May 10 to October 19, 1907, by R. B. Dole, Chase Palmer, and W. D. Collins.

[b] Fe_2O_3.

Mineral analyses of water from Pedee River near Pedee, N. C.[a]

[Parts per million, unless otherwise stated.]

Date (1906–7). From—	To—	Turbidity.	Suspended matter.	Coefficient of fineness.	Total iron (Fe).	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.	Mean gage height (feet).[b]
Oct. 26	Nov. 5	40	28	0.70	.....	39	Tr.	9.1	1.6	.....	0.0	34	.....	0.4	3.5	87	3.0
Nov. 6	Nov. 16	90	46	.51	.....	30	0.9	5.7	Tr.	.....	.0	20	....	.6	2.0	62	2.8
Nov. 17	Nov. 29	140	100	.71	.....	32	.9	4.7	Tr.	.....	.0	16	.....	.3	7.5	82	3.9
Nov. 30	Dec. 11	135	88	.65	.....	30	.8	5.5	Tr.	.....	.0	20	.....	.5	7.0	78	2.8
Dec. 12	Dec. 21	140	102	.73	.....	26	.8	6.4	1.2	.....	.0	22	.....	.6	7.5	74	3.1
Dec. 27	Jan. 8	145	108	.75	.....	30	.40	5.2	Tr.	.....	.0	17	.....	.6	4.0	72	3.8
Jan. 9	Jan. 21	15	11	.73	.....	25	.20	7.4	1.6	.....	.0	27	.....	.4	1.7	63	2.8
Jan. 22	Feb. 3	25	16	.64	.....	18	.30	8.4	1.6	.....	.0	32	.....	.9	3.0	58	2.6
Feb. 6	Feb. 19	15	12	.80	.....	13	.20	9.2	1.6	.....	.0	32	.....	.4	4.5	58	2.7
Feb. 20	Mar. 15	40	34	.85	.....	14	.10	12	0.8	.....	.0	41	.....	.4	1.5	64	3.2
Mar. 16	Mar. 30	25	24	.96	.....	18	.10	10	1.2	.....	.0	34	.....	.7	3.5	59	2.8
Mar. 31	Apr. 15	20	18	.90	.....	26	.30	7.6	Tr.	.....	.0	24	.....	.4	2.0	45	3.1
Apr. 16	Apr. 25	120	110	.92	.....	15	.20	7.0	1.2	.....	.0	24	.....	.2	2.0	45	3.1
Apr. 26	May 1	160	168	1.05	.....	18	.40	5.5	1.2	.....	.0	20	.....	.3	3.0	40	3.4
May 2	May 11	100	74	.74	.....	20	[c]1.4	6.5	2.9	7.2	.0	44	4.0	.5	3.0	76	2.9
May 12	May 21	60	44	.73	.....	27	.40	6.7	3.3	7.8	.0	42	3.6	.2	3.5	78	2.5
May 22	June 3	255	211	.77	.....	21	.8	5.1	2.1	11	.0	39	3.6	.4	4.5	74	2.8
June 18	June 28	365	302	.83	.....	26	[c]2.8	4.1	3.7	7.2	.0	39	2.3	.5	3.0	86	3.0
June 29	July 10	375	238	.63	.....	37	Tr.	5.1	1.3	14	.0	48	4.4	1.4	1.4	91	3.2
Aug. 19	Aug. 31	270	128	.47	6.3	34	Tr.	5.8	0.8	13	.0	45	3.9	.9	1.6	86	2.4
Sept. 1	Sept. 13	240	115	.48	10	23	.03	6.8	1.7	9.4	.0	44	3.9	.5	1.1	64	2.3
Sept. 14	Sept. 28	295	199	.67	8.8	35	.03	4.9	1.3	5.4	.0	26	4.7	.7	.7	70	2.8
Oct. 2	Oct. 15	45	42	.93	2.4	26	Tr.	6.6	0.8	6.5	.0	29	3.9	.3	1.2	62	2.4
Oct. 16	Oct. 19	35	34	.97	.....	30	Tr.	9.3	1.7	7.2	.0	43	5.6	1.1	1.1	78	2.2
Mean.....		131	94	.76	.....	26	.31	6.9	1.3	8.9	.0	32	4.0	.6	3.1	69	....
Per ct. of anhydrous residue..		.....	.....	.....	.....	38.8	[d].7	10.3	1.9	13.3	23.6	.....	6.0	.8	4.6	.....	....

[a] Analyses October 26, 1906, to May 1, 1907, by Jas. R. Evans; May 2 to June 28, 1907, by W. D. Collins; June 29 to October 19, by R. B. Dole, Chase Palmer, and W. D. Collins.

[b] Gaging station at Cheraw, S. C., 20 miles below.

[c] Abnormal; computed as HCO_3 in the average.

[d] Fe_2O_3.

Mineral analyses of water from Platte River near Columbus, Nebr.[a]

[Parts per million, unless otherwise stated.]

Date (1906–7). From—	To—	Turbidity.	Suspended matter.	Coefficient of fineness.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.	Mean gage height (feet).
Oct. 1	Oct. 11	20	21	1.05	31	Tr.	56	15	40	0.0	189	112	0.0	12	361	1.8
Oct. 12	Oct. 21	50	41	.82	33	0.10	55	16	40	.0	187	113	.7	11	353	2.2
Oct. 22	Nov. 2	350	311	.89	37	.20	44	.....	34	.0	167	74	.4	8.4	296	3.0
Nov. 3	Nov. 12	625	542	.87	47	.20	52	13	39	.0	181	86	1.8	9.6	349	3.5
Nov. 13	Nov. 22	300	244	.81	32	.20	66	17	50	.0	195	134	.4	13	412	3.2
Nov. 23	Dec. 2	210	178	.85	26	.20	64	17	.....	.0	187	167	Tr.	14	441	3.0
Dec. 3	Dec. 13	180	162	.90	36	.07	73	22	.....	.0	204	.....	.4	19	543	.....
Dec. 14	Dec. 23	50	48	.96	35	.05	77	25	77	.0	220	223	.9	19	561	.....
Dec. 24	Jan. 2	60	46	.77	27	.10	65	25	51	.0	190	181	.9	15	446	.....
Jan. 3	Jan. 12	20	27	1.35	26	.05	71	23	49	.0	207	206	.9	17	510	.....
Jan. 13	Jan. 22	15	.....	.....	32	Tr.	74	21	46	.0	152	191	.7	16	496	.....
Jan. 23	Feb. 1	20	8.0	.40	22	.08	74	23	55	.0	216	186	1.4	17	487	.....
Feb. 2	Feb. 12	15	10	.67	22	.10	73	20	56	.0	198	189	5.2	16	473	.....
Feb. 15	Feb. 24	215	110	.51	31	Tr.	46	15	.....	.0	148	101	2.3	8.5	309	.....
Feb. 25	Mar. 6	115	90	.78	30	Tr.	66	16	52	.0	192	.....	1.4	13	443	.....
Mar. 7	Mar. 16	580	432	.75	35	.9	72	20	52	.0	186	194	2.3	17	530	.....
Mar. 17	Mar. 26	325	264	.84	28	.25	68	23	39	.0	200	.....	2.0	20	522	.....
Mar. 27	Apr. 5	700	534	.76	33	.35	57	16	60	.0	184	172	1.2	16	454	3.2
Apr. 6	Apr. 15	2,000	1,432	.72	26	.35	56	13	47	.0	175	144	2.7	.....	385	3.0
Apr. 16	Apr. 26	800	638	.80	32	.20	63	18	46	.0	182	155	1.6	13	437	2.8
Apr. 27	May 6	900	774	.86	50	1.0	58	14	39	.0	161	130	1.1	10	407	3.2
May 7	May 15	580	385	.66	38	.6	55	16	41	.0	168	128	.9	11	389	2.9
Mean		374	300	.81	32	.20	63	18	48	.0	186	152	1.3	14	437	.....
Per ct. of anhydrous residue		.....	.....	.....	7.6	[b]1	15.0	4.3	11.4	21.8	.....	36.2	.3	3.3	....	.....

[a] Analyses October 1, 1906, to February 12, 1907, by W. M. Barr; February 15 to 24, 1907, by H. S. Spaulding; February 25 to March 6, 1907, by Walton Van Winkle.

[b] Fe_2O_3

Mineral analyses of water from Platte River at Fremont, Nebr.[a]

[Parts per million, unless otherwise stated.]

Date (1906–7).		Turbidity.	Suspended matter.	Coefficient of fineness.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.
From—	To—														
Oct. 10	Oct. 20	100	88	0.88	50	0.10	47	.....	36	0.0	199	37	0.0	4.9	265
Oct. 21	Oct. 31	290	537	1.85	44	.40	44	12	.....	.0	157	51	.9	4.5	246
Nov. 1	Nov. 10	540	632	1.17	49	.40	47	12	32	.0	161	71	1.3	7.3	303
Nov. 11	Nov. 20	400	335	.84	42	.40	54	14	41	.0	.....	97	.9	9.0	359
Nov. 21	Nov. 30	170	174	1.02	43	.16	53	19	.....	.0	184	86	.9	7.7	328
Dec. 1	Dec. 10	270	272	1.01	51	.20	52	14	34	.0	193	107	1.3	8.5	364
Dec. 11	Dec. 20	125	111	.89	46	Tr.	61	16	38	.0	218	111	.4	7.5	385
Dec. 21	Dec. 30	.....	193	.....	44	Tr.	60	14	33	.0	221	93	Tr.	8.1	352
Dec. 31	Jan. 9	80	52	.65	38	.15	53	15	34	.0	185	97	1.4	8.4	339
Jan. 10	Jan. 27	10	13	1.30	47	Tr.	62	13	40	.0	237	79	1.3	7.8	391
Jan. 28	Feb. 6	10	10	1.00	47	.15	57	15	34	.0	209	80	1.9	7.1	335
Mar. 13	Mar. 22	675	442	.65	40	.28	53	13	31	.0	199	82	Tr.	8.8	341
Mar. 24	Apr. 5	460	544	1.18	35	.32	57	16	32	.0	192	95	.6	7.1	387
Apr. 6	Apr. 17	1050	814	.77	44	.30	47	11	26	.0	176	75	.8	6.9	298
Apr. 18	Apr. 27	540	477	.88	49	.45	.....	13	33	.0	181	83	Tr.	10	347
Apr. 28	May 8	510	536	1.05	62	.6	45	11	37	.0	168	71	1.1	5.4	322
May 9	May 18	.....	.....	.....	50	.40	49	12	.....	.0	170	71	.7	5.7	308
May 19	May 29	485	649	1.34	50	.40	43	13	24	.0	168	57	2.3	4.8	280
May 30	June 8	700	980	1.40	44	.23	41	9.3	23	.0	160	51	2.4	6.7	256
June 9	June 18	600	804	1.34	41	.12	38	8.3	23	.0	160	50	3.0	4.0	251
June 20	June 29	625	514	.82	55	.8	40	11	27	.0	169	52	1.8	3.8	283
June 30	July 10	850	689	.81	.....	.10	41	5.9	29	.0	154	45	1.8	4.5	228
July 11	July 20	1,050	1,725	1.64	51	.8	38	4.4	25	.0	142	42	2.4	2.6	241
July 21	July 30	500	427	.85	32	.08	39	4.5	.....	.0	152	49	.9	.....	337
July 31	Aug. 10	375	343	.91	42	.20	41	8.7	34	.0	186	49	Tr.	6.5	260
Aug. 11	Aug. 20	450	332	.74	45	.15	44	10	27	.0	167	64	.9	5.7	274
Aug. 21	Aug. 31	95	100	1.05	49	.15	43	9.9	25	.0	166	51	Tr.	5.0	274
Sept. 1	Sept. 10	230	224	.97	44	.12	43	9.5	24	.0	165	46	1.8	4.8	253
Sept. 11	Sept. 21	90	93	1.03	63	.10	45	8.2	15	[b] 4.8	161	37	0.3	6.6	271
Sept. 22	Oct. 1	95	99	1.04	62	.10	40	4.2	20	[b] 4.8	155	24	0.3	3.0	243
Oct. 2	Oct. 11	200	168	.84	60	.66	41	8.6	31	[b] 6.0	162	41	1.0	6.0	270
Oct. 12	Oct. 23	75	76	1.01	45	.06	45	9.4	32	[b] 4.8	167	58	0.5	7.4	280
Oct. 24	Nov. 2	100	87	.87	51	.14	46	9.7	32	[b] 6.0	160	61	0.8	7.8	290
Mean		379	392	1.03	47	.26	47	11	30	.0	178	66	1.0	6.4	302
Per ct. of anhydrous residue		.....	.....	.....	15.9	[c] 1	15.9	3.7	10.1	29.6	.....	22.3	.3	2.1	.....

[a] Analyses October 10, 1906, to February 6, 1907, by W. M. Barr; March 13, to September 10, 1907, by Walton Van Winkle; September 11 to November 2, 1907, by R. B. Dole, Chase Palmer, and W. D. Collins.
[b] Abnormal; computed as HCO_3 in the average.
[c] Fe_2O_3.

Mineral analyses of water from Potomac River at Cumberland, Md.[a]

[Parts per million, unless otherwise stated.]

Date (1906–7). From—	To—	Turbidity.	Suspended matter.	Coefficient of fineness.	Total iron (Fe).	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.	Mean gage height (feet).
Sept. 11	Sept. 20	10	13	1.30	1.4	9.0	Tr.	39	7.4	8.5	0.0	46	96	1.7	12	204	3.1
Sept. 21	Sept. 30	6	12	2.00	.1	12	Tr.	45	8.6	12	.0	51	117	.5	16	234	2.6
Oct. 1	Oct. 11	18	19	1.06	2.1	6.0	0.20	33	5.6	4.9	.0	51	59	.5	9.0	157	2.4
Oct. 12	Oct. 21	21	19	.90	1.7	8.0	.10	30	4.8	9.3	.0	43	62	.8	11	150	2.7
Oct. 22	Oct. 31	8	17	2.13	.9	6.4	.20	19	3.2	7.4	.0	37	34	.3	5.0	97	3.5
Nov. 1	Nov. 10	8	6.0	.75	1.2	7.4	.05	27	4.4	8.0	.0	45	53	.0	9.5	134	3.5
Nov. 12	Nov. 21	14	14	1.00	1.1	5.0	.14	29	4.6	8.5	.0	42	63	Tr.	9.8	144	3.6
Nov. 22	Dec. 2	8	7.8	.98	.9	7.0	.30	20	3.8	.....	.0	22	36	1.0	6.7	98	3.4
Dec. 3	Dec. 12	29	26	.90	1.6	10	.20	20	3.4	.....	.0	30	34	1.0	7.2	100	4.1
Dec. 13	Dec. 22	27	25	.93	1.7	13	.20	13	2.6	6.6	.0	39	24	.9	4.1	80	5.7
Dec. 23	Jan. 1	34	34	1.00	2.1	5.2	.16	17	3.8	4.9	.0	36	42	1.5	3.8	84	4.3
Jan. 2	Jan. 11	22	23	1.04	2.1	5.2	.20	15	3.4	4.4	.0	32	37	1.4	2.8	79	5.0
Jan. 12	Jan. 21	80	78	.97	6.6	5.8	.15	12	2.6	4.7	.0	19	26	2.0	3.8	63	7.4
Jan. 22	Jan. 31	28	20	.71	2.8	14	.06	23	5.8	19	[b]12	22	76	1.4	4.4	159	5.1
Feb. 1	Feb. 10	26	8.0	.32	1.9	14	.09	23	5.4	4.4	.0	25	64	1.8	3.4	128	3.7
Feb. 11	Feb. 20	26	9.4	.37	1.9	6.8	.08	23	5.2	4.3	.0	29	63	1.8	3.4	122	3.6
Feb. 21	Mar. 2	33	6.8	.21	1.6	5.8	.08	22	4.8	3.2	.0	28	55	1.2	3.8	111	3.9
Mar. 3	Mar. 12	37	12	.32	2.1	5.8	.10	17	3.2	3.3	.0	28	38	1.9	2.9	84	4.8
Mar. 13	Mar. 23	280	89	.32	9.1	16	.30	14	2.8	4.3	.0	20	39	2.0	1.4	89	8.0
Mar. 24	Apr. 4	21	29	1.38	1.9	4.8	.06	30	7.4	4.4	.0	11	97	1.4	3.8	155	5.0
Apr. 5	Apr. 14	7	11	1.57	3.2	7.2	.09	31	4.2	10	.0	22	93	0.9	5.3	168	4.0
Apr. 15	Apr. 24	35	46	1.32	4.4	6.2	.12	18	3.8	9.9	.0	23	45	1.0	4.8	100	3.9
Apr. 25	May 4	21	40	1.90	5.8	11	.15	17	3.0	8.0	.0	26	36	.9	3.4	90	4.0
May 5	May 14	13	26	2.00	2.6	16	.10	17	3.2	7.7	.0	30	39	.8	2.9	101	4.8
May 15	May 24	11	20	1.82	3.0	6.2	.12	20	4.0	17	.0	43	45	.7	8.2	118	4.4
May 25	June 3	21	30	1.43	2.5	6.6	.14	17	3.0	26	.0	53	40	.6	14	134	4.2
June 4	June 14	20	31	1.55	4.6	8.4	.14	17	3.0	7.4	.0	25	41	1.1	2.4	91	4.2
June 15	June 24	10	22	2.20	1.4	7.0	.10	20	4.4	7.9	.0	25	51	1.0	4.1	107	3.9
June 25	July 5	3	25	8.33	.3	7.0	.06	32	6.8	10	[b]7.2	28	82	Tr.	6.0	166	3.8
July 6	July 15	3	15	5.00	2.6	8.8	.08	38	.....	.....	[b]2.4	29	99	.6	6.2	186	3.9
July 16	July 25	35	42	1.20	7.9	5.0	.22	21	4.0	.....	[b]9.6	9.0	41	.0	3.8	98	3.8
July 27	Aug. 5	15	32	2.13	3.5	4.2	.06	24	4.6	5.7	[b]8.4	13	50	Tr.	5.4	113	3.2
Aug. 6	Aug. 15	25	39	1.56	9.6	6.8	.11	.....	.....	12	.0	41	54	.2	7.4	132	2.6
Aug. 16	Aug. 25	40	145	3.63	8.8	7.4	.06	41	7.8	14	.0	48	91	1.0	12	197	2.3
Aug. 26	Sept. 4	8	14	1.75	2.1	.....	.60	32	6.4	.....	.0	72	57	.6	8.4	194	2.3
Sept. 5	Sept. 14	18	22	1.22	1.8	12	.09	42	.....	20	.0	61	95	.4	13	215	2.5
Mean		28	29	1.59	3.0	8.2	.14	24	4.6	9.0	.0	36	58	.9	6.4	130	....
Per ct. of anhydrous residue		....	....	.....	.....	6.4	c.2	18.6	3.5	7.0	13.7	....	45.0	.7	4.9	....	....

[a] Analyses September 11 to November 21, 1906, by R. B. Dole; November 22, 1906, to April 4, 1907, by R. B. Dole and M. G. Roberts; April 5 to July 5, 1907, by Chase Palmer, and M. G. Roberts; July 6 to September 14, 1907, by R. B. Dole, Chase Palmer, and W. D. Collins.

[b] Abnormal; computed as HCO_3 in the average.

[c] Fe_2O_3.

Mineral analyses of water from Raritan River at Bound Brook, N. J.[a]

[Parts per million, unless otherwise stated.]

Date. (1906–7).		Turbidity.	Suspended matter.	Coefficient of fineness.	Total iron (Fe).	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.	Mean gage height (feet).
From—	To—																
Sept. 10	Sept. 19	9	8.6	0.96	0.1	22	Tr.	14	5.0	10	0.0	65	10	0.8	4.6	102	1.4
Sept. 20	Sept. 29	155	88	.57	2.0	15	0.5	13	4.6	9.9	.0	57	12	1.9	4.6	93	1.6
Sept. 30	Oct. 9	42	39	.93	4.3	14	.20	12	4.4	7.4	.0	59	12	1.8	4.2	92	1.8
Oct. 10	Oct. 19	8	10	1.25	.2	15	.10	14	4.8	7.9	.0	58	13	1.8	5.3	89	1.4
Oct. 20	Oct. 29	32	38	1.19	1.4	23	.20	13	5.2	9.5	.0	56	10	1.7	6.0	97	1.9
Oct. 30	Nov. 8	13	16	1.23	.6	18	.09	12	5.0	7.4	.0	57	10	1.6	5.3	98	1.6
Nov. 9	Nov. 18	9	4.4	.49	.5	14	.14	12	5.6	7.6	.0	59	12	.3	5.0	85	1.6
Nov. 19	Nov. 29	12	19	1.58	.15	12	.08	11	5.2	7.9	.0	52	14	.6	4.9	80	2.0
Nov. 30	Dec. 9	6	6.6	1.10	.2	18	.09	13	5.4	7.6	.0	62	9.9	2.0	4.7	93	1.4
Dec. 10	Dec. 19	26	33	1.27	.9	20	.16	12	4.8	6.6	.0	50	13	1.9	4.6	88	2.1
Dec. 21	Dec. 30	28	41	1.47	1.0	14	.18	10	4.4	6.1	.0	39	11	3.0	4.6	79	2.0
Dec. 31	Jan. 9	37	45	1.22	1.4	14	.30	9.6	4.2	.....	.0	....	12	2.1	4.6	73	2.8
Jan. 10	Jan. 19	47	71	1.51	1.6	11	.17	9.2	2.8	.....	.0	34	13	.....	5.3	69	3.1
Jan. 30	Feb. 9	5	0.8	.16	.4	17	.10	9.6	3.8	7.2	.0	45	10	3.8	4.8	75	1.8
Feb. 10	Feb. 19	4	Tr.	.....	.2	19	.08	11	5.2	9.4	.0	52	8.6	4.0	5.9	83	1.6
Feb. 20	Mar. 2	5	Tr.	.....	.2	22	.09	12	5.0	7.7	.0	52	11	2.4	5.3	89	1.4
Mar. 3	Mar. 12	11	13	1.18	.8	22	.10	10	4.8	9.0	.0	45	13	3.0	4.8	82	2.1
Mar. 13	Mar. 22	80	118	1.48	3.3	21	.20	7.2	2.6	6.0	.0	30	11	2.1	4.1	69	4.9
Mar. 23	Apr. 1	7	9.2	1.30	.4	12	.09	8.2	4.0	6.3	.0	38	10	2.8	3.8	64	2.2
Apr. 2	Apr. 11	10	15	1.50	.4	17	.09	11	2.4	11	.0	43	11	3.0	3.7	76	1.9
Apr. 12	Apr. 21	5	4.2	.84	.2	20	.11	10	3.0	12	.0	44	11	2.9	3.8	81	1.8
Apr. 22	May 2	40	29	.72	.8	17	.21	10	3.4	9.8	.0	45	11	2.8	3.8	81	1.8
May 3	May 12	20	27	1.35	.7	26	.18	10	3.6	9.0	.0	44	12	2.7	3.6	90	2.2
May 13	May 22	45	52	1.16	1.6	24	.13	11	3.8	.....	.0	46	11	2.7	3.5	86	2.2
May 23	June 2	8	15	1.88	.3	11	.06	11	3.6	7.6	.0	52	8.9	2.3	3.6	74	1.8
June 3	June 12	18	17	.94	.6	8.2	.08	9.6	3.0	11	.0	47	10	2.3	3.8	67	1.7
June 13	June 21	5	8.4	1.68	.2	10	.08	13	4.4	8.4	.0	59	10	2.2	4.2	81	1.3
June 23	July 2	18	22	1.22	.3	8.0	.03	13	5.2	11	.0	67	11	1.7	4.6	88	1.3
July 3	July 12	130	133	1.02	4.7	20	.11	17	2.4	12	.0	57	14	.7	4.6	96	1.3
July 13	July 23	272	202	.74	7.0	9.6	.18	14	3.8	11	.0	50	15	.7	4.8	81	1.4
July 24	Aug 2	25	30	1.20	1.4	13	.05	17	1.8	12	.0	56	17	.4	5.4	92	1.1
Aug. 3	Aug. 12	8	15	1.88	.8	10	.05	18	.....	.....	.0	43	18	.3	4.8	88	1.1
Aug. 13	Aug. 23	7	13	1.86	.6	8.4	.07	18	.....	.....	.0	66	18	.4	5.8	93	1.0
Aug. 24	Sept. 3	45	29	.63	1.2	15	.16	17	1.2	12	.0	62	16	.9	5.4	97	1.4
Sept. 5	Sept. 12	120	79	.66	2.6	19	.7	16	1.6	14	.0	56	18	1.0	5.4	104	1.5
Mean		37	36	1.16	1.2	16	.15	12	3.9	9.1	.0	51	12	1.9	4.7	85	....
Per ct. of anhydrous residue		....	....	....	....	18.8	[b].3	14.1	4.6	10.7	29.6	....	14.1	2.3	5.5	....	....

[a] Analyses September 9 to October 29, 1906, and from November 9 to November 29, 1906, by R. B. Dole; October 30 to November 8, 1906, and from November 30, 1906, to April 1, 1907, by R. B. Dole and M. G. Roberts; April 2 to July 2, 1907, by Chase Palmer and M. G. Roberts; July 3 to September 12, 1907, by R. B. Dole, Chase Palmer, and W. D. Collins.

[b] Fe_2O_3.

Mineral analyses of water from Red River near Shreveport, La.[a]

[Parts per million, unless otherwise stated.]

Date. (1907–8).		Turbidity.	Suspended matter.	Coefficient of fineness.	Total iron (Fe).	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.	Mean gage height (feet).
From—	To—																
Mar. 19	Mar. 28	820	780	0.95	.....	40	3.6	57	11	....	0.0	98	99	1.0	42	350	10.8
Mar. 29	Apr. 7	1,050	910	.87	.....	34	3.2	38	19	....	.0	122	67	.1	45	324	6.0
Apr. 8	Apr. 17	600	555	.92	.....	31	1.2	45	.....	48	.0	134	62	.5	58	348	6.0
Apr. 18	Apr. 28	750	.....	.....	.....	28	3.4	38	.....	....	.0	117	76	.4	42	318	3.9
Apr. 29	May 8	900	784	.87	.....	25	3.0	39	.....	27	.0	119	71	.5	40	298	10.6
May 9	May 18	1,100	1,284	1.16	40	55	1.9	35	6.7	21	7.2	117	24	1.2	13	257	17.0
May 23	June 3	880	960	1.09	27	36	.88	36	5.8	30	2.4	110	39	1.0	26	236	18.0
June 4	June 13	1,160	1,589	1.37	38	57	.82	45	6.4	38	14	122	44	1.2	34	311	23.8
June 14	June 23	800	582	.73	22	28	.19	47	7.7	38	Tr.	130	52	.5	41	286	24.7
June 24	July 4	1,400	1,314	.94	35	25	.14	73	13	74	.0	150	128	.4	103	491	14.8
July 5	July 16	1,500	1,800	1.20	42	38	.56	78	15	74	9.6	74	165	Tr.	117	584	11.1
July 17	July 27	1,600	1,850	1.15	40	38	1.8	57	10	42	4.8	102	88	.5	76	377	10.8
July 28	Aug. 7	1,100	1,750	1.59	25	47	.52	91	19	90	8.4	165	162	.3	110	636	4.0
Aug. 8	Aug. 17	290	300	1.04	5.3	30	.22	120	28	101	14	176	240	.2	132	797	2.6
Aug. 19	Aug. 28	300	420	1.40	13	26	.58	122	30	125	6.0	190	247	.3	188	877	1.2
Aug. 29	Sept. 8	170	184	1.08	2.9	39	.24	152	39	172	8.4	278	300	Tr.	252	1,131	.2
Sept. 9	Sept. 18	125	134	1.07	2.7	40	.14	140	39	148	.0	305	271	.2	216	1,035	— .5
Sept. 19	Sept. 28	40	80	2.00	1.3	33	Tr.	221	55	436	.0	232	561	Tr.	700	2,198	—1.2
Sept. 30	Oct. 10	350	438	1.25	13	24	.10	154	47	230	Tr.	288	320	.3	339	1,311	— .4
Oct. 11	Oct. 22	2,800	3,925	1.40	160	9.2	.5	97	22	134	4.8	80	217	Tr.	205	761	6.3
Oct. 23	Nov. 2	1,600	1,200	.75	49	20	.14	135	32	194	Tr.	156	320	.5	292	1,087	1.0
Nov. 3	Nov. 12	300	254	.85	12	20	Tr.	125	26	131	12	212	228	.2	188	851	.2
Nov. 13	Nov. 23	1,600	1,550	.97	100	23	.15	126	30	197	7.2	152	282	.5	292	1,057	1.3
Nov. 25	Dec. 4	425	508	1.19	27	13	.52	42	8.3	40	12	85	62	Tr.	55	276	6.8
Dec. 5	Dec. 15	325	263	.81	15	18	.52	50	12	52	19	51	86	Tr.	71	346	4.9
Dec. 16	Dec. 25	400	447	1.12	13	20	.52	49	13	58	Tr.	111	86	.2	78	357	6.8
Dec. 26	Jan. 4	1,300	1,400	1.08	50	35	3.5	38	4.4	25	Tr.	112	38	.8	24	240	12.6
Jan. 5	Jan. 15	425	616	1.45	21	25	1.2	42	6.3	47	.0	93	71	.5	65	315	10.8
Jan. 16	Jan. 25	300	377	1.26	8.4	35	1.3	31	4.3	36	4.8	83	41	.0	42	248	9.6
Jan. 26	Feb. 4	200	194	.97	8.9	20	.47	46	5.6	53	Tr.	88	82	.4	82	350	6.0
Feb. 5	Feb. 15	240	279	1.16	8.2	15	.6	39	6.5	43	14	61	64	Tr.	55	273	7.6
Feb. 16	Feb. 29	960	1,065	1.11	12	38	2.8	34	4.9	25	7.2	93	39	.5	24	234	13.0
Mar. 1	Mar. 10	240	260	1.08	7.7	28	1.5	34	5.6	31	.0	95	52	.3	35	237	9.9
Mar. 11	Mar. 19	800	660	.82	16	33	2.4	37	5.9	32	Tr.	98	59	.2	38	277	8.9
Mean		790	870	1.11	.....	30	1.1	74	17	90	4.6	135	140	.4	121	561	.....
Per ct. of anhydrous residue		.....	.....	.....	.....	5.5	[b].3	13.6	3.1	16.5	13.1	....	25.7	.0	22.2	.....	.....

[a] Analyses March 19 to May 8, 1907, by James R. Evans; May 9 to March 19, 1907, by R. B. Dole, Chase Palmer, and W. D. Collins.

[b] Fe_2O_3.

Mineral analyses of water from Rio Grande River at Laredo, Tex.[a]

[Parts per million, unless otherwise stated.]

Date. (1905–6).		Suspended matter.	Silica (SiO_2).	Oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Total dissolved solids.	Mean gage height (feet).
From—	To—													
Aug. 1	Aug. 10	4,210	35	5.0	137	18	104	9.5	0.0	164	446	128	772	6.7
Aug. 11	Aug. 20	3,750	40	3.4	204	25	102	9.9	.0	159	267	143	1,090	7.1
Aug. 21	Aug. 30	3,196	33	3.0	117	14	118	7.2	.0	166	202	111	664	5.7
Aug. 31	Sept. 9	892	32	3.8	98	20	96	5.2	.0	178	185	144	676	4.8
Sept. 10	Sept. 20	4,964	31	2.4	104	19	65	4.9	.0	185	202	152	746	6.5
Sept. 21	Sept. 30	3,064	33	2.2	87	14	64	3.6	.0	165	164	77	540	6.6
Oct. 1	Oct. 10	2,872	33	2.6	67	10	51	5.2	.0	161	88	71	436	6.9
Oct. 11	Oct. 20	2,056	39	3.0	97	17	.....	6.5	.0	178	138	134	600	5.3
Oct. 21	Oct. 30	722	36	4.6	98	20	104	9.6	.0	195	192	134	684	4.2
Oct. 31	Nov. 9	354	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	836	3.8
Nov. 10	Nov. 19	762	22	2.4	110	25	.....	.....	.0	190	233	203	864	4.6
Nov. 20	Nov. 29	1,222	27	3.2	76	15	.....	.....	.0	153	155	139	612	5.2
Nov. 30	Dec. 9	470	27	2.6	108	26	122	4.9	.0	176	252	182	904	4.9
Dec. 11	Dec. 19	1,772	28	2.0	107	23	98	12	.0	165	243	144	812	4.7
Dec. 20	Dec. 29	2,246	23	2.6	87	18	72	4.7	.0	.....	191	113	612	5.4
Dec. 30	Jan. 8	696	24	3.2	92	20	97	4.5	.0	.....	192	149	720	4.6
Jan. 9	Jan. 18	396	26	4.4	112	31	122	5.9	.0	212	268	201	956	4.0
Jan. 19	Jan. 28	212	30	3.6	149	35	153	6.0	.0	245	298	240	1,080	3.6
Jan. 29	Feb. 7	128	29	4.0	142	35	142	3.7	.0	185	330	241	1,112	3.5
Feb. 8	Feb. 17	358	17	4.6	130	34	118	3.1	.0	188	322	241	1,072	4.2
Feb. 18	Feb. 27	754	23	2.6	82	19	141	11	.0	126	192	82	668	5.1
Feb. 28	Mar. 9	562	25	1.0	83	22	103	5.4	.0	160	193	120	690	4.4
Mar. 10	Mar. 19	408	34	1.8	104	29	143	3.9	.0	.....	254	.....	916	3.6
Mar. 20	Mar. 29	270	33	4.0	112	34	147	.....	[b]6.3	175	294	227	1,004	3.1
Mar. 30	Apr. 8	208	25	4.0	105	28	145	.....	.0	169	297	265	1,054	2.9
Apr. 9	Apr. 18	396	35	4.0	107	38	190	.....	.0	166	319	304	1,040	3.2
Apr. 19	Apr. 28	406	27	3.4	103	36	162	.....	.0	159	310	292	1,072	3.0
Apr. 29	May 8	1,828	26	10.2	131	38	205	8.9	.0	255	309	346	1,304	4.3
May 9	May 18	5,826	31	6.2	151	31	131	5.9	.0	225	368	275	1,094	4.9
May 19	May 28	5,320	22	5.8	83	27	81	5.1	.0	204	168	121	580	5.0
May 29	June 7	3,446	35	3.2	85	20	89	4.4	.0	170	210	154	752	5.4
June 8	June 17	6,428	29	7.0	89	25	86	5.7	.0	172	193	115	654	4.6
June 18	June 2	5,310	26	3.4	97	20	137	10	.0	172	236	166	782	4.2
June 28	July 7	7,726	19	1.6	64	18	78	8.8	.0	157	146	105	524	4.8
July 8	July 17	6,734	21	2.4	68	12	65	6.8	.0	171	112	103	480	7.3
July 18	July 27	6,382	35	2.4	72	11	82	7.4	[b]13	150	116	74	466	8.4
July 28	Aug. 2	5,226	32	2.2	69	10	72	6.3	[b]6.3	147	118	50	410	9.5
Mean		2,475	29	3.6	104	23	112	6.6	.0	178	228	164	791	.....
Per ct. of anhydrous residue		.....	3.8	.5	13.7	3.0	14.8	.9	11.6	.....	30.1	21.6	.....	.....

[a] Analyses by W. H. Heileman.
[b] Abnormal; computed as HCO_3 in the average.

Mineral analyses of water from Roanoke River at Randolph, Va.[a]

[Parts per million, unless otherwise stated.]

Date. (1906–7). From—	To—	Turbidity.	Suspended matter.	Coefficient of fineness.	Total iron (Fe).	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.
Sept. 7	Sept. 16	500	40	0.08	14	25	2.5	10	4.4	6.5	0.0	57	3.6	0.5	2.4	102
Sept. 17	Sept. 26	300	56	.19	14	24	1.5	8.8	2.8	6.9	.0	55	3.8	.3	2.6	90
Sept. 27	Oct. 4	270	328	1.22	15	16	1.2	9.0	3.2	6.3	.0	48	4.0	Tr.	1.9	74
Oct. 10	Oct. 25	290	282	.97	14	23	2.1	8.4	2.6	.....	.0	45	3.0	.7	1.9	84
Oct. 26	Nov. 5	38	38	1.00	2.6	19	.4	11	4.4	6.6	.0	59	4.3	.5	2.2	76
Nov. 6	Nov. 17	21	21	1.00	1.2	22	.3	11	4.4	7.4	.0	61	4.9	.6	2.5	80
Nov. 18	Nov. 27	350	272	.78	15	23	1.3	8.8	3.8	7.2	.0	50	5.7	.9	1.9	82
Dec. 1	Dec. 15	17	19	1.12	1.4	29	.4	11	4.6	2.8	.0	61	4.4	.5	2.9	87
Dec. 16	Dec. 27	....	156	.....	7.7	20	1.0	9.2	3.8	3.9	.0	50	4.3	.4	2.6	75
Dec. 28	Jan. 6	....	139	.....	7.3	19	1.6	8.8	3.6	5.4	.0	56	4.1	.9	2.3	72
Jan. 7	Jan. 16	26	39	1.50	1.9	23	.6	9.4	3.8	2.5	.0	52	4.6	.6	2.4	69
Jan. 17	Jan. 26	23	23	1.00	2.1	25	.6	10	4.0	4.5	.0	54	4.6	.4	2.9	81
Jan. 27	Feb. 5	26	24	.92	2.3	18	.5	9.6	3.6	3.2	.0	51	4.1	.3	2.6	68
Feb. 6	Mar. 2	60	63	1.05	3.9	13	.5	9.4	2.8	4.4	.0	46	4.8	.3	2.2	62
Mar. 3	Mar. 12	....	192	.....	7.7	25	1.0	8.8	3.2	7.2	.0	44	4.8	1.0	1.3	87
Mar. 13	Mar. 25	29	63	2.17	1.6	17	.19	8.4	2.6	7.1	[b]8.2	34	4.3	.0	1.7	65
Mar. 26	Apr. 4	65	77	1.18	2.1	13	.32	9.8	3.0	7.6	.0	51	4.8	.2	2.0	64
Apr. 5	Apr. 14	171	139	.81	6.5	24	1.0	9.6	3.2	7.6	.0	50	4.9	1.0	1.4	83
Apr. 19	Apr. 29	290	238	.82	18	28	1.0	10	3.4	7.2	.0	55	5.1	1.0	2.2	91
Apr. 30	May 12	400	327	.82	16	22	1.0	9.6	3.2	8.5	.0	58	4.1	.5	2.6	85
Mean		169	127	.....	7.7	21	.95	9.5	3.5	5.9	.0	53	4.4	.5	2.2	79
Per ct. of anhydrous residue						28.2	[c]1.8	12.8	4.7	7.9	35.1	.....	5.9	.7	3.0	.....

[a] Analyses September 7 to November 27, 1906, by R. B. Dole; December 1, 1906, to April 4, 1907, by R. B. Dole and M. G. Roberts; April 5 to May 12, 1907, by Chase Palmer and M. G. Roberts.

[b] Abnormal; computed as HCO_3 in the average.

[c] Fe_2O_3.

Mineral analyses of water from St. Lawrence River at Ogdensburg, N. Y.[a]

[Parts per million, unless otherwise stated.]

Date (1906-7).	Turbidity.	Suspended matter.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.	Mean gage height (feet).
Sept. 18	2	....	9.6	0.06	32	6.9	6.2	4.2	114	12	Tr.	7.7	135	244.93
Oct. 18	1	....	8.2	.03	32	6.5	6.7	3.7	115	12	Tr.	7.2	134	244.68
Nov. 18	5	....	3.7	.05	31	7.3	6.1	4.2	114	12	0.6	7.6	128	244.62
Dec. 24	2	....	6.6	.04	32	7.1	5.7	Tr.	123	13	.45	7.6	133	244.64
Jan. 18	3	....	6.6	.04	31	7.4	6.9	3.6	117	13	.25	7.8	135	245.20
Mar. 18	18	....	5.0	.05	31	7.3	5.4	Tr.	120	13	.25	7.7	128	245.42
Apr. 23	4	....	7.7	.05	30	7.7	7.3	2.5	116	12	.15	7.3	141	245.32
May 22	1	....	7.1	.06	30	7.6	6.8	4.0	113	12	.15	7.2	143	245.74
June 18	.....	.....	3.9	.05	32	6.9	6.1	0.0	118	12	.8	7.9	130	246.05
July 20	.....	.....	5.2	.03	32	7.4	5.8	4.4	112	14	.6	8.6	133	246.12
Aug. 18	.....	.....	9.4	.04	32	7.3	6.1	4.8	111	12	.4	8.3	137	245.90
Mean	4.5	Tr.	6.6	.05	31	7.2	6.3	2.9	116	12	0.3	7.7	134	.....
Per ct. of anhydrous residue	.....	.....	5.0	[b].1	23.6	5.5	4.8	45.7	.....	9.2	0.2	5.9	.....	.....

[a] Analyses by R. B. Dole and M. G. Roberts.
[b] Fe_2O_3.

Mineral analyses of water from Saluda River near Columbia, S. C.[a]

[Parts per million, unless otherwise stated.]

Date (1906-7). From—	To—	Turbidity.	Suspended matter.	Coefficient of fineness.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).[b]	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).[c]	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.	Mean gage height (feet).[d]
Oct. 27	Nov. 5	70	35	0.50	23	1.0	6.3	0.8	.....	0.0	27	.....	0.3	4.0	63	1.4
Nov. 6	Nov. 16	95	30	.32	26	.8	4.2	Tr.	.....	.0	.....	.....	.5	4.0	55	1.5
Nov. 17	Nov. 28	40	21	.52	23	.6	9.1	1.2	.....	.0	34	.....	.5	1.0	68	1.7
Nov. 29	Dec. 8	35	18	.51	20	.30	10	1.6	.....	.0	39	.....	.7	2.0	70	4.2
Dec. 9	Dec. 19	85	60	.71	20	.5	3.9	Tr.	.....	.0	.....	.....	.8	2.2	48	5.2
Jan. 4	Jan. 15	25	17	.68	32	.20	11	2.0	.....	.0	44	.....	.5	2.5	80	5.6
Jan. 16	Jan. 25	45	34	.76	19	.40	12	2.4	.....	.0	44	.....	.5	2.5	66	3.6
Jan. 26	Feb. 4	60	46	.77	17	.20	8.4	1.2	.....	.0	29	.....	.3	5.0	60	3.8
Feb. 5	Feb. 14	70	55	.78	27	.30	7.2	.8	.....	.0	24	.....	.3	4.0	67	4.5
Feb. 15	Feb. 24	55	33	.60	15	.20	9.6	Tr.	.....	.0	29	.....	.1	3.5	50	3.2
Feb. 25	Mar. 14	65	48	.74	18	.20	10	1.2	.....	.0	34	.....	.5	4.5	62	3.6
Mar. 15	Mar. 24	45	40	.89	21	.10	9.6	1.6	.....	.0	34	.....	.4	3.0	64	2.1
Mar. 25	Apr. 3	18	17	.94	19	.10	10	1.2	.....	.0	34	.....	.4	4.5	60	2.0
Apr. 4	Apr. 13	15	12	.80	20	.....	10	1.6	.....	.0	34	.....	.4	5.0	71	2.7
Apr. 14	Apr. 23	250	230	.92	20	.5	7.5	2.8	.....	.0	32	.....	.3	4.5	57	2.6
Apr. 24	May 3	185	166	.90	22	.30	6.0	2.4	.....	.0	24	.....	.4	4.0	55	5.2
Mean		72	54	.71	21	.38	8.4	1.3	[b]6.0	.0	33	[c]5.0	.43	3.5	62	....
Per ct. of anhydrous residue[e]		.....	.....	.....	33.6	[f].9	13.5	2.1	9.6	26.0	.....	8.0	.7	5.6	....	....

[a] Analyses by J. R. Evans.
[b] Fluctuates between 1 and 10 parts; average value about 6 parts.
[c] Fluctuates between trace and 10 parts; average value about 5 parts.
[d] Gaging station at Chappells, S. C., 50 miles above.
[e] Approximate.
[f] Fe_2O_3.

Mineral analyses of water from Savannah River near Augusta, Ga.[a]

[Parts per million, unless otherwise stated.]

Date (1906–7).		Turbidity.	Suspended matter.	Coefficient of fineness.	Total iron (Fe).	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.	Mean gage height (feet).
From—	To—																
Oct. 25	Nov. 3	45	33	0.73	.....	21	.....	5.4	1.2	.....	0.0	27	.....	0.1	3.0	56	9.6
Nov. 4	Nov. 13	40	17	.42	.....	28	0.20	6.2	Tr.	.....	.0	24	.....	.6	3.0	77	9.0
Nov. 14	Nov. 23	35	12	.34	.....	32	.30	4.4	Tr.	.....	.0	17	.....	.7	1.5	59	10.4
Nov. 24	Dec. 3	40	17	.42	.....	32	.20	4.9	Tr.	.....	.0	20	.....	.8	1.5	64	9.2
Dec. 4	Dec. 13	55	20	.36	.....	34	.30	6.4	3.2	.....	.0	22	.....	.6	1.8	74	9.6
Dec. 14	Dec. 23	65	22	.34	.....	31	.30	6.2	2.8	.....	.0	22	.....	.5	2.0	72	10.8
Dec. 24	Jan. 2	85	55	.65	.....	36	.40	3.9	Tr.	.....	.0	15	.....	.3	3.0	78	11.0
Jan. 3	Jan. 12	60	46	.77	.....	24	.7	3.9	1.6	.....	.0	17	.....	.8	2.5	54	11.2
Jan. 13	Jan. 22	16	10	.62	.....	17	.40	6.0	4.8	.....	.0	27	.....	.8	3.0	60	9.3
Jan. 23	Feb. 2	60	41	.68	.....	30	.40	8.2	2.8	.....	.0	34	.....	.4	3.5	70	9.3
Feb. 3	Feb. 12	150	127	.85	.....	23	.7	5.4	.8	.....	.0	20	.....	.9	3.0	53	14.2
Feb. 13	Feb. 22	20	17	.85	.....	13	1.2	7.6	1.2	.....	.0	24	.....	.6	3.0	52	9.2
Mar. 13	Mar. 22	22	15	.68	.....	12	.9	5.6	Tr.	.....	.0	20	.....	.6	2.8	42	9.4
Mar. 23	Apr. 1	15	14	.93	.....	20	.9	8.4	Tr.	.....	.0	27	.....	.5	3.0	55	8.4
Apr. 2	Apr. 11	45	42	.93	.....	23	1.2	8.4	Tr.	.....	.0	27	.....	.3	2.5	59	8.5
Apr. 12	Apr. 21	210	205	.98	.....	26	1.4	7.6	Tr.	.....	.0	24	.....	.3	1.5	52	8.4
Apr. 22	May 1	340	316	.93	.....	20	1.6	5.5	Tr.	.....	.0	19	.....	.4	3.0	42	11.6
May 2	May 11	265	248	.94	.....	17	1.8	7.2	1.6	.....	.0	24	.....	.2	3.0	45	9.5
May 12	May 22	45	38	.84	3.2	37	.22	5.9	.4	13	.0	50	5.5	.8	1.7	90	8.3
May 23	June 1	130	142	1.09	5.2	31	.20	5.2	.4	13	[b] 9.6	27	5.7	.7	1.8	78	8.3
June 2	June 11	175	259	1.65	14	21	.54	4.9	.4	11	[b] 7.2	17	6.1	.7	1.4	61	9.8
June 12	June 21	300	231	.77	9.6	17	.08	5.1	.2	12	[b]Tr.	35	5.6	1.1	1.4	51	8.2
June 22	July 3	425	338	.79	14	15	.06	5.1	.4	11	[b]Tr.	37	5.8	1.6	1.6	54	8.8
July 4	July 13	315	255	.81	9.4	25	.20	5.0	.7	12	[b] 7.2	24	5.5	.2	1.4	67	7.7
July 14	July 23	425	446	1.05	18	30	.26	5.0	.....	12	[b]14	9.8	7.3	.9	1.2	76	8.4
July 24	Aug. 3	400	419	1.05	14	14	.04	4.7	.4	13	[b] 9.6	22	7.4	.0	Tr.	53	7.6
Aug. 4	Aug. 13	575	424	.74	46	15	Tr.	5.1	.6	11	.0	32	6.8	3.0	1.8	53	7.4
Aug. 14	Aug. 23	475	318	.67	28	16	.04	5.1	.5	10	[b] 3.6	30	6.7	.3	1.7	56	9.5
Aug. 24	Sept. 2	160	75	.47	7.9	22	Tr.	5.0	.5	13	.0	40	6.0	1.0	2.0	63	6.5
Sept. 3	Sept. 12	270	159	.59	11	18	.04	5.0	.4	11	.0	34	5.3	1.0	2.2	58	6.8
Sept. 13	Sept. 22	200	72	.36	9.3	19	.00	6.0	.5	12	.0	40	5.8	.7	2.2	64	6.1
Sept. 23	Oct. 2	300	299	1.00	21	14	.04	6.0	.3	9.2	.0	33	4.9	.0	1.6	49	10.9
Oct. 3	Oct. 12	65	59	.91	5.6	16	Tr.	4.6	.4	9.6	.0	32	4.7	.7	1.9	53	6.3
Oct. 13	Oct. 22	25	25	1.00	2.4	21	.00	5.3	.5	11	[b] 2.4	32	6.0	.0	1.8	61	5.3
Mean		172	142	.77	.....	23	.44	5.7	.8	12	.0	30	6.0	.6	2.1	60	.....
Per ct. of anhydrous residue		.....	.....	.....	.....	35.0	[c] .9	8.7	1.2	18.3	22.6	.....	9.1	1.0	3.2	.....	.....

[a] Analyses October 25, 1906, to May 11, 1907, by J. R. Evans; May 12 to October 22, 1907, by R. B. Dole, Chase Palmer, and W. D. Collins.

[b] Abnormal; computed as HCO_3 in the average.

[c] Fe_2O_3.

Mineral analyses of water from Shenandoah River at Millville, W. Va.[a]

[Parts per million, unless otherwise stated.]

Date (1906–7).		Turbidity.	Suspended matter.	Coefficient of fineness.	Total iron (Fe).	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.	Mean gage height (feet).
From—	To—																
Sept. 12	Sept. 21	17	18	1.06	0.3	16	Tr.	35	11	5.0	0.0	156	3.6	2.1	2.6	149	1.4
Sept. 22	Oct. 1	12	11	.92	.2	12	0.10	35	12	6.2	.0	160	3.4	2.0	3.2	150	1.3
Oct. 2	Oct. 11	42	30	.71	.8	19	.05	33	9.4	5.8	.0	142	5.1	2.6	3.0	146	2.2
Oct. 12	Oct. 21	80	69	.86	2.1	20	.20	28	8.0	6.0	.0	118	6.1	2.1	2.4	131	3.9
Oct. 22	Oct. 31	90	108	1.20	2.6	20	.20	28	7.4	5.8	.0	116	4.6	3.4	2.4	131	4.6
Nov. 1	Nov. 10	9	7	.78	Tr.	19	Tr.	38	6.8	5.7	Tr.	163	6.1	3.0	2.4	162	2.2
Nov. 11	Nov. 20	9	10	1.11	.1	16	.05	42	7.6	4.9	6.0	161	5.8	3.0	2.4	172	1.8
Nov. 21	Nov. 30	37	32	.86	1.4	14	.20	29	7.2	5.2	Tr.	122	6.5	3.0	2.6	126	2.9
Dec. 1	Dec. 10	7	5.0	.71	.1	16	.05	37	9.8	5.5	6.0	147	7.1	3.2	2.6	155	1.7
Dec. 11	Dec. 20	25	27	1.08	.3	19	.06	36	11	5.7	.0	155	5.9	3.2	2.6	157	2.4
Dec. 21	Dec. 30	27	21	.78	.5	13	.16	30	8.0	3.2	Tr.	120	5.4	3.5	2.2	124	2.7
Dec. 31	Jan. 10	28	23	.82	1.0	12	.14	30	7.4	4.3	.0	120	5.9	3.0	2.6	126	2.9
Jan. 11	Jan. 20	27	26	.96	.9	14	.10	32	7.6	4.1	.0	129	6.6	3.0	2.8	136	3.1
Jan. 21	Jan. 30	28	31	1.11	1.1	11	.12	31	7.0	3.3	.0	120	4.8	3.0	2.4	123	3.2
Jan. 31	Feb. 9	10	11	1.10	.4	10	.08	.....	10	4.1	.0	144	5.8	3.2	3.0	151	2.2
Feb. 10	Feb. 19	9	12	1.33	.5	14	.06	36	9.4	4.9	5.8	137	8.1	3.6	3.4	148	2.5
Feb. 20	Feb. 28	11	11	1.00	.4	17	.07	36	9.0	5.4	.0	145	7.1	4.2	3.0	150	2.2
Mar. 2	Mar. 11	.....	203	.....	3.7	16	.13	34	8.4	4.9	.0	142	6.9	4.3	2.9	146	2.5
Mar. 12	Mar. 21	75	71	.95	1.5	10	.16	31	7.4	4.7	.0	127	5.3	4.1	2.9	126	3.3
Mar. 22	Mar. 31	19	16	.84	.5	16	.05	30	7.8	4.7	2.4	122	6.1	3.7	2.3	132	2.4
Apr. 1	Apr. 10	11	11	1.00	1.1	20	.07	35	9.6	9.1	.0	.....	6.6	3.7	2.2	154	....
Apr. 11	Apr. 20	75	78	1.04	2.1	26	.13	28	6.4	5.8	4.8	107	5.9	3.4	3.8	138	....
Apr. 21	Apr. 30	4	8.0	2.00	.2	20	.07	31	7.6	6.0	4.8	110	5.6	2.0	4.2	138	....
May 1	May 11	5	10	2.00	.3	18	.06	32	8.0	6.9	3.6	116	5.9	2.6	3.8	137	....
May 12	May 21	3	8.5	2.83	.3	16	.05	28	7.8	8.5	.0	122	6.1	1.7	3.0	134	....
May 22	May 31	9	13	1.44	.4	12	.06	31	7.6	.....	.0	123	4.9	2.3	3.0	134	....
June 1	June 10	150	161	1.08	4.0	14	.06	24	5.4	6.3	.0	102	5.8	2.0	3.0	112	....
June 11	June 20	85	115	1.35	1.9	11	.08	14	5.4	5.4	.0	71	5.3	Tr.	1.8	78	....
June 21	June 30	2	19	9.50	.3	14	.08	32	9.2	6.6	2.4	127	4.9	1.8	3.6	139	....
July 1	July 10	15	64	4.26	.5	14	.05	26	5.6	13	4.8	108	7.9	1.3	2.6	122	1.8
July 11	July 20	7	24	3.43	.2	11	.04	36	.....	11	4.8	142	8.1	1.5	3.0	149	1.5
July 21	July 31	5	16	3.20	.2	11	.03	37	9.8	12	.0	159	8.7	2.0	4.2	158	1.4
Aug. 1	Aug. 10	38	35	.92	.6	8.6	.03	35	.....	8.8	.0	149	8.4	1.0	3.8	145	1.1
Aug. 11	Aug. 20	4	14	3.50	.3	8.6	.03	37	.....	9.0	.0	152	8.1	2.1	3.4	152	1.3
Aug. 21	Aug. 30	20	18	.90	.4	13	.05	38	7.8	12	2.4	149	7.9	2.4	3.8	158	1.4
Aug. 31	Sept. 9	80	58	.72	1.6	15	.06	37	7.4	13	.0	149	7.9	2.1	6.6	160	1.3
Mean		31	39	1.64	.9	15	.08	32	8.2	6.7	1.3	132	6.2	2.6	3.0	140	....
Per ct. of anhydrous residue		....	.....	.....	.....	10.7	b 1	22.8	5.9	4.8	47.3	.....	4.4	1.9	2.1	.....	.....

[a] Analyses September 12 to December 10, 1906, by R. B. Dole; December 11, 1906, to March 31, 1907, by R. B. Dole and M. G. Roberts; April 1 to June 30, 1907, by Chase Palmer and M. G. Roberts; July 1 to September 9, 1907, by R. B. Dole, Chase Palmer, and W. D. Collins.

[b] Fe_2O

Mineral analyses of water from Lake Superior at Sault Ste. Marie, Mich.[a]

[Parts per million, unless otherwise stated.]

Date (1906–7).	Turbidity.	Suspended matter.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.	Mean gage height (feet).[b]
Sept. 22	2	....	11	0.09	13	3.2	3.9	0.0	59	4.1	0.25	1.0	63	602.95
Oct. 22	1	....	8.7	.03	13	3.1	3.5	.0	56	3.8	.25	1.2	61	602.84
Nov. 22	2	....	5.9	.04	13	2.9	2.0	.0	54	1.8	.45	1.4	54	602.66
Dec. 20	Tr.	....	7.2	.08	13	2.9	3.6	.0	55	1.8	.30	1.3	58	602.45
Jan. 22	Tr.	....	4.7	.03	13	2.9	2.0	.0	55	1.6	.45	1.2	53	602.22
Mar. 22	3	....	12	.04	13	3.2	5.1	.0	55	1.7	.35	1.1	68	602.06
Apr. 20	1	....	12	.11	13	3.1	3.5	.0	56	1.5	.30	1.0	64	601.94
May 23	3	....	4.8	.09	13	3.0	3.0	.0	52	1.5	.55	1.0	57	602.10
June 22	3	....	4.6	.04	14	3.2	3.3	.0	59	1.7	1.2	1.2	59	602.55
July 22	2	....	5.7	.05	12	3.0	2.8	.0	58	1.5	1.2	1.0	55	602.70
Aug. 22	5	....	5.3	.05	13	3.1	2.9	.0	60	1.6	.50	1.1	66	602.93
Mean	2	Tr.	7.4	.06	13	3.1	3.2	.0	56	2.1	.5	1.1	60	.....
Per ct. of anhydrous residue	....	....	12.7	c.2	22.4	5.3	5.5	47.5	....	3.6	.9	1.9	.....	.....

[a] Analyses by R. B. Dole and M. G. Roberts.
[b] Gaging station at Marquette, Mich., 160 miles west.
[c] Fe_2O_3.

Mineral analyses of water from Susquehanna River at West Pittston, Pa.[a]

[Parts per million, unless otherwise stated.]

Date. (1906–7). From—	To—	Turbidity.	Suspended matter.	Coefficient of fineness.	Total iron (Fe).	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.	Mean gage height (feet).[b]
Oct. 28	Nov. 7	5	3.8	0.76	0.3	12	0.04	15	2.4	4.1	0.0	61	8.2	0.3	3.1	79	5.11
Nov. 8	Nov. 16	3	0.6	.20	1.0	10	.03	16	3.0	4.7	.0	62	8.1	.4	3.0	77	4.24
Nov. 28	Dec. 7	8	8.2	1.02	.4	8.4	.03	15	2.8	4.4	.0	56	8.5	1.0	2.0	72	5.33
Dec. 8	Dec. 17	37	41	1.11	1.4	10	.13	16	2.0	6.5	.0	58	12	3.0	4.1	79	8.11
Dec. 19	Dec. 28	12	18	1.50	.9	8.4	.14	16	1.6	6.5	.0	58	11	2.0	4.1	76	6.80
Dec. 29	Jan. 7	150	145	.97	5.1	10	.21	12	1.4	6.6	.0	47	10	3.0	3.6	68	11.50
Jan. 8	Jan. 18	27	42	1.55	1.5	10	.19	13	1.6	5.0	.0	38	15	3.6	3.6	70	10.10
Jan. 19	Jan. 29	21	34	1.62	1.5	8.0	.16	14	1.6	5.5	.0	46	13	3.0	3.4	69	10.10
Jan. 30	Feb. 10	2	4.6	2.30	.6	8.8	.14	19	2.4	5.4	.0	54	18	6.0	4.6	89	8.20
Feb. 11	Feb. 20	2	2.8	1.40	.3	16	.10	20	2.6	6.6	.0	72	13	4.0	4.6	95	5.60
Feb. 21	Mar. 3	2	5.8	2.90	.4	8.2	.12	22	3.2	7.4	c 2.9	81	12	2.2	5.0	100	4.10
Mar. 4	Mar. 13	2	4.2	2.10	.7	9.0	.10	.....	3.2	.....	.0	83	12	3.2	5.9	103	3.40
Mar. 14	Mar. 23	65	59	.91	2.6	12	.13	12	2.6	6.8	7.2	25	10	2.6	2.2	69	10.90
Mar. 24	Apr. 2	33	33	1.00	1.8	5.4	.13	10	2.0	.....	.0	26	11	1.6	1.4	50	11.80
Apr. 3	Apr. 14	8	20	2.50	.9	12	.21	16	2.2	6.8	.0	56	9.2	2.0	3.6	82	6.40
Apr. 15	Apr. 24	....	4.2	.....	.4	14	.19	21	3.4	6.3	.0	....	17	2.0	4.2	98	6.10
Apr. 25	May 4	43	77	1.79	1.5	15	.22	24	3.9	5.8	.0	....	18	1.5	4.8	102	10.40
May 5	May 14	1	10	10.00	.5	18	.15	26	6.0	9.0	.0	96	18	1.7	4.2	134	7.50
May 15	May 24	2	20	10.00	.3	9.2	.29	12	4.2	9.0	c 4.8	36	18	.0	5.0	80	5.60
May 25	June 3	2	15	7.50	.3	6.4	.15	.....	4.2	9.1	c 4.8	35	19	Tr.	5.0	82	4.70
June 4	June 13	3	36	12.00	.4	12	.27	14	4.2	8.2	c 4.8	43	20	Tr.	5.0	91	4.80
June 14	June 23	1	18	18.00	.2	10	.17	12	4.2	7.1	c 12	27	17	Tr.	5.0	80	3.60
June 24	July 3	2	27	13.50	.3	3.4	.06	14	4.6	11	.0	54	20	Tr.	7.0	86	3.60
July 4	July 13	Tr.	3.0	.....	.....	23	.05	26	5.8	11	.0	98	21	.8	6.6	148	4.00
July 14	July 24	Tr.	6.2	.....	.....	14	.06	27	6.2	3.8	.0	....	17	1.0	4.6	117	4.00
July 25	Aug. 4	Tr.	5.4	.....	.....	7.8	.06	26	4.4	3.5	.0	82	14	.8	4.6	108	3.30
Aug. 5	Aug. 15	Tr.	3.4	.....	.....	9.0	.05	24	4.8	4.6	.0	85	11	.8	4.6	106	2.70
Aug. 16	Aug. 25	Tr.	3.2	.....	.....	5.4	.05	25	6.6	3.3	.0	85	11	.4	4.6	100	2.40
Aug. 27	Sept. 6	8	11	1.38	.....	14	.11	26	2.9	9.1	.0	95	12	.3	5.4	120	2.30
Sept. 7	Sept. 16	18	19	1.06	.....	8.4	.15	20	4.0	3.5	.0	66	13	.3	4.6	91	5.00
Sept. 17	Sept. 26	Tr.	7.0	.....	.....	8.0	.06	17	3.0	5.5	.0	61	14	1.0	2.2	85	4.10
Sept. 27	Oct. 9	5	7.6	1.52	.3	13	.06	20	1.8	.....	.0	67	12	Tr.	3.6	97	4.90
Oct. 10	Oct. 22	3	16	5.33	.7	4.0	.06	17	2.9	1.9	.0	55	9.7	.5	2.4	71	6.30
Mean		14	22	4.00	1.0	10	.12	18	3.4	6.3	.0	63	14	1.5	4.2	90	.....
Per ct. of anhydrous residue		....	.....	.....	.....	11.3	d .2	20.4	3.8	7.1	35.0	....	15.8	1.7	4.7	.....	.....

[a] Analyses October 28, 1906, to April 2, 1907, by R. B. Dole and M. G. Roberts; April 3 to July 3, 1907, by Chase Palmer and M. G. Roberts; July 4 to October 22, 1907, by R. B. Dole, Chase Palmer, and W. D. Collins.

[b] Gaging station at Wilkes-Barre, Pa., 10 miles above.

[c] Abnormal; computed as HCO_3, in the average.

[d] Fe_2O_3.

Mineral analyses of water from Susquehanna River at Williamsport, Pa.[a]

[Parts per million, unless otherwise stated.]

Date (1906–7). From—	To—	Turbidity.	Suspended matter.	Coefficient of fineness.	Total iron (Fe).	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.	Mean gage height (feet).
Sept. 21	Sept. 30	8	8.0	1.00	0.1	7.6	0.10	17.0	4.6	9.9	0.0	40	41	0.5	5.4	110	0.93
Oct. 1	Oct. 10	7	7	1.00	.3	5.2	.10	17	6.2	8.0	.0	38	42	.9	2.0	123	1.14
Oct. 11	Oct. 21	13	16	1.23	.3	9.0	Tr.	14	3.0	7.6	.0	33	34	.6	4.6	97	1.86
Oct. 22	Oct. 31	9	11	1.22	.1	13	Tr.	8.4	1.8	6.0	.0	30	17	.4	2.6	68	3.15
Nov. 1	Nov. 10	5	4.2	.84	.4	5.4	.13	10	2.2	7.7	.0	24	23	.5	3.4	63	2.03
Nov. 11	Nov. 21	6	3.0	.50	.4	5.4	.16	11	3.0	.....	.0	27	21	.5	3.5	66	1.86
Nov. 22	Dec. 2	8	7.2	.90	.6	5.2	.11	8.0	1.8	.....	.0	20	17	.6	2.6	52	3.06
Dec. 3	Dec. 12	14	21	1.50	1.3	5.6	.14	8.4	2.0	6.9	.0	17	18	.6	2.9	55	3.22
Dec. 13	Dec. 22	12	10	.83	1.0	6.2	.15	7.8	2.4	4.9	.0	14	19	1.3	3.4	50	3.63
Dec. 23	Jan. 1	11	21	1.90	.8	6.2	.11	8.4	2.4	5.4	.0	18	20	1.5	3.4	55	2.99
Jan. 2	Jan. 11	19	34	1.79	2.1	6.2	.12	6.2	1.8	4.6	.0	15	16	1.9	2.9	45	6.78
Jan 22	Feb. 1	7	13	1.85	.6	5.8	.11	8.8	2.4	3.8	.0	15	18	1.4	2.4	49	4.96
Feb. 2	Feb. 11	1	0.8	.80	.2	4.0	.06	11	3.2	3.9	.0	18	27	1.8	4.1	62	2.79
Feb. 12	Feb. 21	4	1.8	.45	.5	6.2	.09	13	3.6	5.7	.0	20	32	1.6	4.7	73	2.27
Feb. 22	Mar. 3	2	0.8	.40	.3	5.8	.10	14	3.8	5.5	.0	22	34	1.6	5.0	79	1.80
Mar. 4	Mar. 13	3	1.5	.50	.4	5.2	.19	14	4.0	6.0	.0	22	32	1.6	5.8	78	2.69
Mar. 14	Mar. 23	95	170	1.79	7.2	13	.25	9.6	1.8	5.5	.....	.....	18	.9	1.7	55	10.89
Mar. 24	Apr. 3	13	35	2.69	1.0	14	.12	10	2.2	8.4	.....	.....	13	.4	7.7	69	7.20
Apr. 4	Apr. 13	12	9.2	.77	.6	8.0	.13	8.2	2.2	8.2	.....	.....	19	Tr.	3.4	52	3.37
Apr. 14	Apr. 23	1	3.4	.34	.5	9.4	.17	9.0	2.1	8.8	.....	.....	20	1.2	3.4	62	2.64
Apr. 24	May 3	4	16	.40	1.0	16	.15	6.6	1.6	7.4	.....	.....	14	1.0	2.4	54	5.02
May 4	May 13	1	14	14.00	.9	7.4	.14	6.6	1.5	4.9	.....	.....	14	Tr.	2.4	41	4.67
May 14	May 23	3	13	4.33	.6	18	.12	7.5	1.7	7.7	.....	.....	16	Tr.	2.4	64	3.32
May 24	June 2	Tr.	4.6	.....	.2	4.6	.12	9.6	2.2	.....	.....	.....	21	Tr.	2.4	55	2.22
June 3	June 12	9	29	3.22	1.4	3.6	.11	7.1	1.7	.....	.0	19	15	Tr.	2.2	44	4.60
June 13	June 23	1	12	12.00	.5	9.8	.12	9.0	2.2	7.4	.....	.....	20	Tr.	2.4	62	2.65
June 24	July 3	78	78	1.00	2.2	12	.12	11	2.0	.....	[b] 4.8	16	19	Tr.	3.6	73	3.72
July 4	July 13	8	15	1.88	.....	8.0	.06	8.7	3.4	2.6	.0	23	18	.6	2.2	57	2.98
July 14	July 23	4	15	3.75	.....	6.8	.11	13	4.5	2.2	.0	29	26	.2	3.4	72	1.61
July 24	Aug. 2	Tr.	14	.....	.....	2.8	.15	17	4.9	2.5	.0	26	37	Tr.	4.2	81	1.04
Aug. 3	Aug. 12	Tr.	10	.....	.....	3.8	.12	17	5.4	2.8	.0	32	37	.2	4.8	93	.67
Aug. 13	Aug. 22	3	13	4.33	.....	5.6	.13	19	7.1	5.3	.0	40	45	.2	6.0	111	.50
Aug. 23	Sept. 1	Tr.	5.2	.....	.....	5.4	.16	22	7.9	6.0	.0	55	39	1.0	6.6	117	.36
Sept. 2	Sept. 11	Tr.	4.6	.....	.....	8.6	.14	23	7.9	6.6	.0	55	42	.9	6.2	128	.58
Sept. 12	Sept. 21	2	.....	.....	.....	5.8	.05	22	6.4	5.8	.0	38	51	.0	7.8	122	1.19
Sept. 22	Oct. 2	4	4.4	1.10	.3	11	.08	24	5.4	7.7	.0	44	.....	1.1	7.2	120	1.20
Oct. 3	Oct. 11	8	7.0	.88	.6	5.6	.06	17	3.6	.....	.0	.....	38	.5	6.2	90	2.03
Mean		10	18	2.23	.9	7.6	.11	12	3.4	6.0	.0	28	26	.7	4.0	74	.....
Per ct. of anhydrous residue		.....	.....	.....	.....	10.3	[c].2	16.3	4.6	8.1	18.8	.....	35.3	1.0	5.4	.....	.....

[a] Analyses September 21 to October 31, 1906, by R. B. Dole; November 1, 1906, to March 13, 1907, by R. B. Dole and M. G. Roberts; March 14 to April 3, 1907, by M. G. Roberts; April 4 to July 3, 1907, by Chase Palmer and M. G. Roberts; July 4 to October 11, 1907, by R. B. Dole, Chase Palmer, and W. D. Collins.

[b] Abnormal; computed as HCO_3 in the average.

[c] Fe_2O_3.

Mineral analyses of water from Susquehanna River at Danville, Pa.[a]

[Parts per million, unless otherwise stated.]

Date (1906–7).		Turbidity.	Suspended matter.	Coefficient of fineness.	Total iron (Fe).	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.	Mean gage height (feet).
From—	To—																
Sept. 10	Sept. 20	3	.....	.....	.....	15.0	0.30	.....	.....	7.2	0.0	48	39	0.2	4.2	124	2.50
Sept. 21	Sept. 30	4	1.6	0.40	Tr.	14	Tr.	22.0	6.2	11	.0	55	53	.8	4.9	141	2.40
Oct. 1	Oct. 10	22	18	.82	0.4	8.2	Tr.	.....	5.0	8.7	.0	48	35	.4	4.3	105	2.79
Oct. 11	Oct. 20	5	6	1.20	.1	6.4	Tr.	18	5.2	8.2	.0	47	28	1.5	5.0	98	2.90
Oct. 21	Oct. 31	29	61	2.10	2.3	7.0	.05	18	5.6	8.0	.0	67	17	1.3	4.8	98	5.01
Nov. 1	Nov. 10	8	8.0	1.00	.3	6.0	.06	13	2.6	6.6	.0	45	15	.0	3.1	73	4.71
Nov. 11	Nov. 20	9	7.8	.87	.3	6.0	.05	16	3.4	7.2	.0	56	22	Tr.	4.7	88	3.95
Nov. 21	Nov. 30	19	40	2.10	1.8	3.8	.18	12	2.8	6.5	.0	41	13	.3	2.2	64	6.12
Dec. 1	Dec. 10	13	14	1.08	.6	7.6	.09	17	4.0	8.4	.0	51	24	2.6	5.8	92	5.25
Dec. 11	Dec. 21	19	21	1.10	1.0	9.6	.10	15	3.6	8.2	.0	50	20	2.6	5.3	86	5.75
Dec. 23	Jan. 1	22	23	1.04	.8	14	.10	19	5.4	9.4	.0	52	25	5.6	8.6	112	4.83
Jan. 2	Jan. 11	53	80	1.51	2.1	6.4	.19	9.4	3.0	4.7	.0	28	13	2.0	2.3	55	10.52
Jan. 12	Jan. 21	41	18	.44	1.5	15	.26	15	4.0	16	[b]14	40	22	3.0	5.8	121	7.14
Jan. 22	Jan. 31	8	13	1.63	.9	23	.10	30	.....	9.8	.0	76	42	11	16	178	6.10
Feb. 1	Feb. 11	12	2.2	.18	.7	8.0	.06	27	6.0	10	.0	68	39	7.2	12	140	3.94
Feb. 13	Feb. 22	15	4.4	.29	.7	5.2	.06	32	7.2	12	[b]4.8	67	40	7.2	13	152	3.28
Feb. 23	Mar. 4	6	2.2	.37	.3	11	.06	25	6.4	8.0	.0	61	41	3.6	6.5	134	.....
Mar. 5	Mar. 14	30	30	1.00	1.0	9.0	.05	26	6.4	12	.0	66	42	7.0	9.8	142	4.38
Mar. 15	Mar. 24	55	71	1.29	3.0	15	.15	6.4	1.4	4.9	.0	24	10	1.9	2.4	56	9.70
Mar. 25	Apr. 3	19	26	1.37	1.4	6.4	.12	11	2.2	5.4	.0	34	14	2.0	3.4	62	9.24
Apr. 4	Apr. 13	10	12	1.20	.5	6.0	.08	20	2.8	9.8	[b]3.4	43	22	5.3	10	104	5.26
Apr. 14	Apr. 23	11	13	1.18	.6	12	.08	19	2.2	11	[b]Tr.	44	22	5.2	9.4	99	5.18
Apr. 24	May 3	42	54	1.28	1.9	12	.13	12	1.0	8.2	.0	43	14	3.1	5.3	76	7.82
May 4	May 13	18	19	1.06	.8	12	.10	18	1.4	8.0	.0	48	18	3.0	7.0	95	6.37
May 14	May 23	8	9.4	1.18	.5	9.6	.06	19	1.6	13	.0	58	20	6.1	9.6	108	4.95
May 24	June 2	40	43	1.08	1.0	13	.18	22	1.6	12	.0	65	21	5.1	9.4	120	4.10
June 3	June 12	3	5.2	1.73	.3	7.2	.03	19	1.2	8.8	.0	48	21	6.2	11	100	4.36
June 13	June 22	3	5.2	1.73	.2	6.2	.05	25	4.0	13	.0	65	30	6.2	14	138	3.41
June 23	July 2	40	39	.97	.4	4.0	.03	23	5.6	5.7	.0	....	32	3.7	12	126	3.19
July 3	July 12	8	34	4.25	.8	6.0	.06	21	4.8	7.9	.0	51	31	2.8	10	116	3.86
July 13	July 23	8	21	2.62	.5	4.2	.06	23	5.6	5.2	.0	55	32	1.8	10	121	3.63
July 24	Aug. 2	1	16	16.00	.3	4.8	.06	22	5.0	9.9	[b]6.0	41	37	1.8	11	122	3.08
Aug. 3	Aug. 12	Tr.	4.8	.....	.2	4.0	.05	28	6.8	9.0	.0	60	47	3.0	11	143	2.59
Aug. 13	Aug. 22	Tr.	4.6	.....	.2	4.0	.05	32	9.8	7.7	.0	62	63	3.0	13	170	2.24
Aug. 23	Sept. 1	Tr.	9.0	.....	.1	2.8	.04	34	10	11	[b]6.0	50	71	2.9	13	177	2.12
Sept. 2	Sept. 11	7	10	1.43	.4	.....	.12	35	11	9.0	.0	79	71	2.9	11	....	2.52
Mean		16	21	1.73	.8	8.7	.09	21	4.6	8.9	.0	54	31	3.4	8.1	112	.....
Per ct. of anhydrous residue		....	.....	.....	.....	7.7	[c].1	18.7	4.1	7.9	23.7	....	27.6	3.0	7.2	....	.....

[a] Analyses September 10 to November 30, 1906, by R. B. Dole; December 1, 1906, to April 3, 1907, by R. B. Dole and M. G. Roberts; April 4 to July 2, 1907, by Chase Palmer and M. G. Roberts; July 3 to September 11, 1907, by R. B. Dole, Chase Palmer, and W. D. Collins.

[b] Abnormal; computed as HCO_3 in the average.

[c] Fe_2O_3.

Mineral analyses of water from Tennessee River near Knoxville, Tenn.[a]

[Parts per million, unless otherwise stated.]

Date (1906–7). From—	To—	Turbidity.	Suspended matter.	Coefficient of fineness.	Total iron (Fe).	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.	Mean gage height (feet).
Oct. 26	Nov. 4	48	21	0.44	.....	18	0.40	26	1.6	.....	0.0	83	.....	0.2	6.0	111	2.5
Nov. 5	Nov. 14	75	28	.37	.....	26	.6	18	.....	.....	.0	59	.....	.8	.....	93	1.9
Nov. 15	Nov. 24	280	212	.76	.....	29	.8	20	3.6	.....	.0	77	.....	.2	12	128	8.4
Nov. 25	Dec. 4	300	194	.65	.....	26	.9	22	4.0	.....	.0	78	.....	.3	12	124	3.4
Dec. 5	Dec. 15	215	173	.81	.....	30	.7	23	2.8	.....	.0	93	.....	.3	10	131	2.4
Dec. 16	Dec. 30	105	79	.75	.....	24	.10	21	2.8	.....	.0	73	.....	.7	18	136	4.2
Dec. 31	Jan. 9	80	64	.80	.....	25	.30	21	1.2	.....	.0	66	.....	.9	7.0	105	5.8
Jan. 10	Jan. 19	25	16	.64	.....	28	.20	20	1.2	.....	.0	68	.....	1.0	10	118	2.8
Jan. 20	Jan. 29	25	15	.60	.....	13	.20	20	2.0	.....	.0	63	.....	.8	12	96	2.8
Jan. 30	Feb. 8	55	33	.60	.....	16	.40	23	3.6	.....	.0	76	.....	.4	4.5	99	3.0
Feb. 25	Mar. 7	45	32	.71	.....	14	.10	24	2.4	.....	.0	80	.....	.4	6.5	103	4.5
Mar. 8	Mar. 17	60	48	.80	.....	10	.40	26	3.2	.....	.0	85	.....	.3	11	114	5.7
Mar. 18	Mar. 27	275	237	.86	.....	37	.20	20	6.4	.....	.0	85	.....	.7	8.5	136	3.4
Mar. 28	Apr. 6	240	193	.80	.....	38	.20	19	.....	.....	.0	78	.....	.4	10	136	2.8
Apr. 7	Apr. 16	135	136	1.01	.....	30	.30	26	.....	.....	.0	98	.....	.2	6.5	133	4.4
Apr. 17	Apr. 26	155	164	1.06	.....	15	.20	22	.....	.....	.0	85	.....	1.1	9.0	105	3.9
Apr. 27	May 6	170	196	1.15	.....	20	.30	20	3.6	.....	.0	73	.....	.9	7.5	99	3.9
May 7	May 14	105	88	.84	.....	12	.20	20	4.4	.....	.0	73	.....	.8	6.5	88	5.1
May 15	May 24	55	58	1.06	.....	15	.20	22	5.5	12	.....	102	4.3	.5	10	109	2.4
May 25	June 3	85	60	.71	.....	12	.40	22	5.7	.....	.....	95	5.0	.5	11	110	2.3
June 4	June 13	325	450	1.38	.....	17	.6	21	4.3	12	.0	90	5.8	1.3	10	120	6.9
June 14	June 23	335	365	1.09	.....	20	.40	24	4.7	.....	.0	103	4.9	2.0	6.0	125	5.6
June 24	July 3	460	290	.63	.....	25	.30	21	5.0	7.9	.0	101	7.2	1.4	7.0	126	2.9
July 4	July 13	267	221	.83	.....	19	.40	20	4.8	.....	.0	99	5.6	.6	9.5	120	2.0
July 14	July 24	310	300	.97	.....	19	.40	23	5.0	8.2	.0	93	8.1	1.1	7.0	118	3.3
Aug. 4	Aug. 13	350	184	.53	9.1	30	1.4	24	5.6	7.2	Tr.[b]	98	6.9	1.2	11	141	1.8
Aug. 14	Aug. 23	425	177	.42	7.2	30	1.1	.....	5.3	9.1	Tr.[b]	101	6.6	1.2	9.6	139	1.7
Aug. 24	Sept. 2	400	202	.50	11	33	1.4	28	5.9	6.9	[b]3.6	89	7.1	1.0	11	143	1.7
Sept. 3	Sept. 13	285	117	.41	6.1	44	1.0	25	6.4	10	[b]3.6	92	7.1	Tr.	17	164	1.8
Sept. 14	Sept. 28	700	506	.72	18	49	1.9	22	5.7	6.6	Tr.[b]	88	8.4	1.5	13	164	3.1
Sept. 30	Oct. 15	110	81	.74	3.8	57	1.1	24	6.5	3.8	[b]4.8	85	6.2	.5	14	162	1.7
Oct. 16	Oct. 26	20	45	2.25	.9	15	.08	26	7.4	6.6	[b]4.8	96	6.5	.....	5.8	119	0.8
Mean		204	156	.81	.....	25	.54	22	4.3	8.2	.0	86	6.4	.8	9.6	122	....
Per ct. of anhydrous residue		.....	.....	.....	.....	21.0	c.6	18.4	3.6	6.9	35.5	....	5.4	.6	8.0	.....	....

[a] Analyses October 26, 1906, to May 14, 1907, by Jas. R. Evans; May 15 to July 24, 1907, by W. D. Collins; August 4 to October 26, 1907, by R. B. Dole, Chase Palmer, and W. D. Collins.

[b] Abnormal; computed as HCO_3 in the average.

[c] Fe_2O_3.

Mineral analyses of water from Tennessee River near Gilbertsville, Ky.[a]

[Parts per million, unless otherwise stated.]

Date (1906–7). From—	To—	Turbidity.	Suspended matter.	Coefficient of fineness.	Total iron (Fe).	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.	Mean gage height (feet).[b]
Oct. 24	Nov. 10	40	35	0.87	.....	30	0.8	11	.....	.....	0.0	56	.....	0.4	2.0	99	6.0
Nov. 11	Nov. 21	290	258	.89	.....	28	.6	12	2.8	.....	.0	51	.....	.8	1.0	94	9.6
Nov. 22	Dec. 10	225	186	.83	.....	36	.40	14	3.2	.....	.0	49	.....	.8	1.5	102	15.4
Dec. 11	Dec. 20	205	161	.78	.....	31	.6	13	4.8	.....	.0	54	.....	1.0	1.5	109	8.1
Dec. 21	Dec. 30	125	94	.75	.....	15	.30	17	3.2	.....	.0	61	.....	.7	7.0	96	11.2
Dec. 31	Jan. 10	270	245	.91	.....	28	.40	14	4.8	.....	.0	61	.....	1.1	3.0	120	19.6
Jan. 11	Jan. 20	30	21	.70	.....	26	.40	16	6.0	.....	.0	71	.....	1.2	2.7	102	10.8
Jan. 21	Jan. 30	35	19	.54	.....	12	.20	19	4.0	.....	.0	76	.....	.5	2.5	88	12.9
Jan. 31	Feb. 9	190	158	.83	.....	27	.40	16	1.2	.....	.0	.....	.....	1.0	2.0	84	18.0
Feb. 10	Feb. 19	95	74	.78	.....	17	.30	17	1.6	.....	.0	68	.....	.4	2.2	85	10.3
Feb. 20	Mar. 1	380	290	.76	.....	26	.40	15	4.4	.....	.0	54	.....	.3	2.0	79	7.3
Mar. 2	Mar. 11	170	142	.84	.....	22	.10	20	4.8	.....	.0	64	.....	.3	1.0	86	22.3
Mar. 12	Mar. 21	210	185	.88	.....	38	.20	24	.....	.....	.0	88	.....	.7	3.8	130	19.2
Mar. 22	Mar. 31	40	32	.80	.....	21	.20	17	5.2	.....	.0	68	.....	.3	2.0	95	12.8
Apr. 1	Apr. 10	210	196	.93	.....	32	.20	22	2.0	.....	.0	73	.....	.1	2.0	112	7.4
Apr. 11	Apr. 22	80	75	.94	.....	16	.40	16	6.0	.....	.0	68	.....	1.3	3.5	82	9.2
Apr. 23	May 2	115	124	1.08	.....	18	.30	17	6.4	.....	.0	73	.....	1.1	4.5	90	10.0
May 3	May 12	105	96	.91	.....	16	.20	18	.....	.....	.0	73	.....	1.0	4.0	90	17.6
May 14	May 24	175	172	.98	.....	.....	1.0	.....	2.8	5.7	.0	61	12	1.8	1.0	106	17.0
May 25	June 3	90	143	1.59	.....	11	.20	22	2.5	9.2	.0	73	13	2.2	1.4	112	7.0
June 4	June 13	50	57	1.14	.....	11	.17	21	4.8	5.4	.0	73	11	Tr.	2.3	91	8.4
June 14	June 25	125	109	.87	.....	6.6	.40	20	4.9	8.6	.0	72	12	4.0	4.8	114	10.8
June 26	July 7	250	201	.80	.....	8.8	.....	26	3.8	3.8	.0	93	11	3.1	2.2	103	6.3
July 8	July 17	140	135	.96	.....	14	.30	21	2.2	7.5	.0	82	12	2.1	1.9	102	4.6
July 18	July 28	160	100	.62	.....	11	.28	21	5.6	10	.0	82	13	1.8	2.9	118	5.3
July 29	Aug. 9	115	76	.66	.....	15	.21	24	5.2	.....	.0	87	13	1.8	4.0	....	3.7
Aug. 10	Aug. 20	75	91	1.21	.....	12	.05	21	4.5	.....	.0	....	14	1.9	2.5	95	3.4
Aug. 21	Aug. 31	85	80	.94	.....	11	.29	21	3.8	6.7	.0	76	14	2.7	4.3	107	3.4
Sept. 2	Sept. 11	80	82	1.02	.....	15	.28	24	5.8	10	.0	88	9.6	0.5	4.0	112	3.1
Sept. 12	Sept. 23	190	106	.56	1.6	20	.6	21	5.3	6.1	.0	87	7.9	2.0	4.2	108	3.3
Sept. 24	Oct. 3	290	170	.59	4.9	27	1.0	21	4.9	5.4	.0	90	7.1	1.2	4.8	121	6.5
Oct. 4	Oct. 14	375	184	.49	7.0	19	1.2	19	3.5	12	[c]4.8	71	7.4	1.1	6.0	107	4.1
Oct. 15	Oct. 24	40	94	2.35	.....	12	.08	20	3.6	9.4	[c]3.6	72	6.4	Tr.	3.0	89	2.5
Mean		153	127	.90	.....	20	.39	19	4.1	7.7	.0	72	11	1.2	3.0	101	.....
Per ct. of anhydrous residue		....	....	.....	.....	19.6	[d].6	18.6	4.0	7.5	34.8	....	10.8	1.2	2.9	....	.....

[a] Analyses October 24, 1906, to May 12, 1907, by J. R. Evans; May 14 to September 11, 1907, by Walton Van Winkle; September 12 to October 24, 1907, by R. B. Dole, Chase Palmer, and W. D. Collins.

[b] Gaging station at Johnsonville, Tenn., 80 miles above.

[c] Abnormal; computed as HCO_3 in the average.

[d] Fe_2O_3.

Mineral analyses of water from Tombigbee River near Epes, Ala.[a]

[Parts per million, unless otherwise stated.]

Date (1906–7).		Turbidity.	Suspended matter.	Coefficient of fineness.	Total iron (Fe).	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.	Mean gage height (feet).
From—	To—																
Oct. 24	Nov. 2	95	61	0.64	.....	37	0.40	12	2.8	.....	0.0	49	.....	0.4	3.5	95	3.7
Nov. 3	Nov. 12	85	60	.70	.....	34	.20	11	2.8	.....	.0	46	.....	.3	3.0	85	1.9
Nov. 13	Nov. 22	90	88	.98	.....	23	.9	17	2.4	.....	.0	71	.....	.3	2.5	104	4.1
Nov. 23	Dec. 2	90	58	.64	.....	36	.30	.....	Tr.	.....	.0	.....	.....	.1	2.0	71	9.8
Dec. 3	Dec. 12	85	54	.63	.....	32	.40	.....	Tr.	.....	.0	.....	.....	.4	1.5	68	5.3
Dec. 13	Dec. 22	95	64	.67	.....	27	.20	.....	Tr.	.....	.0	.....	.....	.6	1.8	57	10.7
Dec. 23	Jan. 1	135	105	.78	.....	40	.40	22	2.4	.....	.0	76	.....	.5	5.0	129	11.2
Jan. 2	Jan. 14	55	39	.71	.....	20	.40	16	.....	.....	.0	73	.....	.4	4.0	100	12.5
Jan. 15	Jan. 24	30	19	.63	.....	19	.8	18	2.0	.....	.0	61	.....	.3	4.5	93	7.0
Jan. 25	Feb. 3	145	100	.69	.....	33	.20	21	1.6	.....	.0	61	.....	.3	3.5	102	10.5
Feb. 4	Feb. 13	130	99	.76	.....	22	.6	12	1.2	.....	.0	41	.....	.8	2.2	75	31.1
Feb. 14	Feb. 24	8	5.6	.70	.....	9.6	.10	12	Tr.	.....	.0	39	.....	.5	3.8	51	7.8
Feb. 25	Mar. 9	380	310	.82	.....	31	.40	22	2.4	.....	.0	68	.....	.2	3.0	118	28.0
Mar. 11	Mar. 20	85	64	.75	.....	19	.40	14	3.2	.....	.0	51	.....	.4	2.5	73	20.6
Mar. 21	Mar. 30	55	48	.87	.....	21	.40	18	5.2	.....	.0	66	.....	.6	3.5	88	8.4
Mar. 31	Apr. 13	140	156	1.12	.....	26	.30	17	2.8	.....	.0	56	.....	.3	3.5	92	5.8
Apr. 14	Apr. 23	320	300	.94	.....	28	.8	20	2.4	.....	.0	68	.....	.4	3.5	97	9.4
Apr. 24	May 3	450	415	.92	.....	33	.9	22	2.4	.....	.0	73	.....	.2	4.0	104	12.3
May 4	May 13	120	95	.79	.....	21	1.0	20	1.6	.....	.0	61	.....	.1	3.5	88	31.2
May 14	May 24	180	118	.66	7.0	15	1.0	20	1.9	8.5	.0	79	6.2	.0	1.8	94	33.8
May 25	June 3	300	179	.60	10	.....	1.6	21	2.6	12	.0	93	5.9	Tr.	1.8	.....	21.6
June 4	June 20	220	129	.59	7.9	23	1.0	22	1.9	8.2	.0	72	6.4	Tr.	1.8	104	12.1
June 22	July 2	260	252	.97	8.8	30	.52	.....	.....	11	.0	90	6.6	Tr.	2.4	127	4.3
July 3	July 12	200	147	.73	8.8	39	1.0	.....	2.0	11	.0	94	7.1	Tr.	2.6	129	3.5
July 13	July 22	45	46	1.02	2.4	27	1.0	23	1.8	12	.0	83	6.7	Tr.	3.2	119	2.9
July 23	Aug. 1	35	28	.80	2.4	25	1.2	19	1.6	10	.0	.....	5.9	Tr.	1.8	96	2.4
Aug. 2	Aug. 11	60	30	.50	3.7	20	1.0	18	1.5	11	.0	.....	7.9	.2	4.2	95	1.7
Aug. 12	Aug. 21	100	78	.78	3.3	23	.32	21	.9	11	.0	75	5.7	1.7	2.6	102	1.6
Aug. 22	Aug. 31	90	47	.52	3.5	29	1.0	22	.8	11	.0	82	6.1	1.5	2.4	115	2.0
Sept. 1	Sept. 24	20	20	1.00	1.5	16	.52	21	.9	8.8	.0	73	4.8	1.4	3.4	94	.7
Sept. 25	Oct. 4	50	60	1.20	1.5	23	.33	18	1.5	12	.0	71	5.2	1.3	3.0	98	1.4
Oct. 5	Oct. 14	20	25	1.25	1.3	10	.24	16	1.0	7.9	.0	50	6.7	5.0	2.6	71	.9
Oct. 15	Oct. 24	10	16	1.60	1.1	18	.98	13	1.2	7.6	.0	46	6.5	1.2	3.0	73	1.0
Mean		126	100	.82	.....	25	.63	18	1.8	10	.0	67	6.3	.6	3.0	94	....
Per ct. of anhydrous residue		....	.....	.....	.....	25.4	[b].9	18.3	1.8	10.1	33.5	....	6.4	.6	3.0	....	....

[a] Analyses October 24, 1906, to May 13, 1907, by J. R. Evans; May 14 to October 14, 1907, by R. B. Dole, Chase Palmer, and W. D. Collins.

[b] Fe_2O_3.

Mineral analyses of water from Wabash River near Logansport, Ind.[a]

[Parts per million, unless otherwise stated.]

Date (1906-7).		Turbidity.	Suspended matter.	Coefficient of fineness.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.
From—	To—														
Sept. 9	Sept. 18	105	80	0.76	.....	0.15	66	62	382	[b]7.9	190	82	0.0	741	1,461
Sept. 19	Sept. 29	50	31	.62	11	Tr.	102	60	.....	.0	259	97	.0	690	1,515
Sept. 30	Oct. 9	20	18	.90	17	.10	109	63	.....	.0	242	100	.0	737	1,596
Oct. 12	Oct. 21	10	3.6	.36	8.0	.10	117	68	434	.0	258	114	Tr.	866	1,785
Oct. 22	Oct. 31	10	6.0	.60	9.6	.20	128	77	473	.0	276	101	.0	915	1,882
Nov. 1	Nov. 10	10	7.2	.72	10	.10	112	.....	478	.0	314	112	.4	960	1,940
Nov. 11	Nov. 20	10	7.4	.74	13	.08	133	74	461	.0	317	138	.0	889	1,905
Nov. 21	Nov. 30	125	128	1.02	11	.20	91	33	169	.0	206	93	18	320	841
Dec. 1	Dec. 10	150	128	.85	19	.40	77	36	112	.0	218	97	11	223	681
Dec. 11	Dec. 21	145	140	.97	22	.85	68	25	61	.0	166	75	11	114	498
Dec. 22	Dec. 31	50	39	.78	17	.20	92	36	105	.0	259	102	18	198	703
Jan. 1	Jan. 10	295	270	.92	29	.....	48	15	34	.0	127	61	9.7	57	323
Jan. 12	Jan. 20	240	205	.85	21	1.2	52	17	28	.0	144	44	13	51	309
Jan. 21	Jan. 30	280	161	.57	27	1.2	52	17	33	.0	150	52	5.6	49	320
Jan. 31	Feb. 9	10	4.4	.44	8.4	.10	97	35	97	.0	298	99	6.4	175	651
Feb. 10	Feb. 20	Tr.	Tr.	.....	16	Tr.	102	36	119	.0	292	94	6.0	222	727
Feb. 21	Mar. 3	10	4.0	.40	10	Tr.	94	35	115	.0	278	111	8.4	204	711
Mar. 4	Mar. 13	370	285	.77	6.4	.05	83	34	118	.0	.....	88	7.3	218	713
Mar. 14	Mar. 23	650	435	.67	38	1.2	43	15	22	.0	116	46	16	35	311
Mar. 24	Apr. 3	145	86	.59	12	.25	57	19	38	.0	187	60	4.4	60	374
Apr. 4	Apr. 14	30	18	.60	10	.20	60	25	83	.0	240	76	6.7	153	559
Apr. 15	Apr. 25	5	Tr.	.....	8.0	.22	.....	33	98	.0	258	87	7.9	222	697
Apr. 26	May 7	10	.....	.....	10	.07	89	36	115	.0	234	89	3.2	223	748
May 8	May 17	8	.....	.....	5.0	.04	87	32	98	.0	242	89	4.3	185	672
May 18	May 28	20	28	1.40	.....	.04	90	33	.....	.0	260	85	4.1	233	713
May 29	June 7	90	99	1.10	9.8	.20	66	22	59	.0	195	60	6.1	117	478
June 8	June 18	150	155	1.03	18	.15	67	18	31	.0	194	42	7.5	63	388
June 19	June 28	230	208	.90	11	.15	61	20	53	.0	207	53	5.0	89	422
June 29	July 8	50	52	1.04	11	.05	88	29	.....	.0	277	63	4.4	188	620
July 10	July 21	900	802	.89	14	.10	63	20	62	.0	195	50	8.8	95	425
July 22	July 31	140	115	.82	11	.02	67	22	53	.0	239	56	2.9	83	434
Aug. 1	Aug. 10	50	116	2.32	11	.05	84	33	102	.0	288	64	2.2	174	659
Aug. 11	Aug. 20	85	74	.87	9.0	.05	85	35	108	.0	292	73	1.8	214	734
Aug. 21	Aug. 30	75	66	.88	20	.05	89	44	176	.0	295	80	1.8	313	932
Aug. 31	Sept. 9	75	84	1.12	9.8	.08	67	24	94	.0	217	48	3.5	150	527
Mean.....		132	117	.85	14	.23	82	35	142	.0	234	79	5.9	292	807
Per ct. of anhydrous residue..		.....	.....	.....	1.8	[c].0	10.7	4.6	18.5	15.1	.....	10.3	.8	38.2	.....

[a] Analyses September 9, 1906, to February 9, 1907, by W. M. Barr; February 10 to March 3, 1907, by H. S. Spaulding; March 4 to September 9, 1907, by Walton Van Winkle.

[b] Abnormal; computed as HCO_3 in the average.

[c] Fe_2O_3.

Mineral analyses of water from Wabash River at Vincennes, Ind.[a]

[Parts per million, unless otherwise stated.]

Date (1906–7). From—	To—	Turbidity.	Suspended matter.	Coefficient of fineness.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.	Mean gage height (feet).[b]
Sept. 9	Sept. 19	50	38	0.76	8.0	0.05	54	26	46	0.0	232	55	1.3	84	421	1.6
Sept. 20	Oct. 1	90	36	.40	5.4	.05	65	24	49	.0	254	56	1.3	90	436	1.3
Oct. 2	Oct. 16	....	21	.....	12	.10	61	25	31	.0	232	64	4.4	60	376	2.3
Oct. 17	Oct. 30	15	18	1.20	12	Tr.	75	26	54	.0	266	68	4.4	89	470	1.4
Oct. 31	Nov. 13	25	26	1.04	10	Tr.	73	30	60	.0	279	60	1.8	104	504	1.1
Nov. 14	Nov. 24	205	187	.91	11	Tr.	68	27	.....	.0	246	65	2.2	84	436	3.9
Nov. 25	Dec. 4	180	181	1.00	12	.25	63	20	36	.0	200	71	11	53	360	9.1
Dec. 5	Dec. 15	290	294	1.02	5.2	.40	64	18	19	.0	188	67	16	29	322	8.9
Dec. 15	Dec. 25	135	164	1.22	12	.40	59	16	21	.0	196	58	18	26	330	13.2
Dec. 26	Jan. 5	190	214	1.13	13	.6	62	22	19	.0	209	61	5.3	21	307	10.5
Jan. 7	Jan. 17	170	122	.72	15	.7	45	16	12	.0	.....	39	13	13	232	22.8
Jan. 18	Jan. 27	315	194	.62	30	.....	.....	.....	8.1	.0	147	39	6.5	8.3	209	23.3
Jan. 28	Feb. 6	120	68	.57	18	.9	47	19	12	.0	168	.....	6.1	8.8	242	19.4
Feb. 7	Feb. 18	40	52	1.30	12	.10	69	23	.....	.0	264	73	8.1	24	348	7.0
Feb. 19	Feb. 28	30	28	.93	12	.05	69	22	25	.0	255	60	8.8	30	358	6.0
Mar. 1	Mar. 10	50	36	.72	15	.15	69	25	29	.0	256	72	8.5	28	356	6.4
Mar. 11	Mar. 25	625	624	1.00	36	1.8	46	22	10	.0	171	46	6.1	21	287	18.6
Mar. 26	Apr. 15	75	70	.93	16	.18	58	17	12	.0	216	.....	7.8	16	288	8.0
Apr. 16	Apr. 24	75	43	.57	9.0	.09	.....	23	20	.0	246	61	7.9	27	339	5.3
Apr. 27	May 8	50	76	1.52	10	.28	62	24	26	.0	228	61	6.9	37	350	7.9
May 10	May 19	85	187	2.20	6.4	.17	61	24	20	.0	264	57	.8	27	335	5.9
May 20	June 1	425	656	1.54	3.0	.21	51	17	19	.0	192	46	6.6	14	268	6.8
June 3	June 13	195	305	1.56	5.6	.01	51	15	13	.0	.....	.....	16	15	295	15.8
June 14	June 26	170	221	1.30	14	.05	62	.....	21	.0	220	51	11	33	329	7.2
June 27	July 7	300	381	1.27	16	.20	62	22	17	.0	255	44	7.5	20	317	6.0
July 8	July 18	280	270	.97	12	.20	62	20	21	.0	252	45	.9	24	316	5.5
July 19	July 31	300	409	1.36	16	.02	53	17	15	.0	208	37	3.5	14	283	8.2
Aug. 1	Aug. 14	450	567	1.26	14	.01	62	20	21	.0	253	50	2.0	13	311	4.3
Aug. 15	Aug. 26	130	156	1.20	13	.09	62	21	24	.0	262	45	1.9	20	302	3.8
Aug. 27	Sept. 6	80	246	3.07	9.2	.04	64	24	29	.0	264	45	1.1	26	322	3.8
Sept. 7	Sept. 16	30	81	2.70	28	.01	61	20	28	.0	241	49	1.1	43	362	3.7
Mean		172	193	1.20	13	.24	61	22	25	.0	230	55	6.4	36	336	.....
Per ct. of anhydrous residue		....	....	.....	3.9	c 1	18.4	6.6	7.5	34.1	.....	16.6	2.0	10.8	.....	.....

[a] Analyses September 9, 1906, to February 6, 1907, by W. M. Barr; February 7 to 28, 1907, by H. S. Spaulding; March 1 to September 16, 1907, by Walton Van Winkle.

[b] Gaging station at Mount Carmel, Ill., 30 miles below.

[c] Fe_2O_3.

Mineral analyses of water from Wateree River near Camden, S. C.[a]

[Parts per million, unless otherwise stated.]

Date (1906–7).		Turbidity.	Suspended matter.	Coefficient of fineness.	Total iron (Fe).	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.	Mean gage height (feet).
From—	To—																
Oct. 21	Oct. 30	70	65	0.93	.....	25	.....	6.8	4.8	.....	0.0	33	.....	0.9	2.5	65	14.8
Nov. 1	Nov. 10	55	13	.24	.....	24	0.5	5.5	.8	.....	.0	22	.....	Tr.	4.0	58	8.3
Nov. 11	Nov. 20	45	21	.47	.....	28	.9	4.7	Tr.	.....	.0	.....	.....	.3	2.0	60	7.7
Nov. 21	Dec. 1	75	28	.37	.....	31	.7	6.0	1.2	.....	.0	22	.....	.4	3.0	70	10.8
Dec. 2	Dec. 13	60	25	.42	.....	28	.8	5.5	1.6	.....	.0	22	.....	.5	2.8	65	8.1
Dec. 14	Dec. 24	85	50	.59	.....	31	.9	6.2	1.6	.....	.0	24	.....	.6	2.5	69	8.8
Dec. 25	Jan. 3	125	62	.50	.....	43	.20	.....	.8	.....	.0	37	.....	.5	4.0	95	10.4
Jan. 4	Jan. 14	75	62	.83	.....	20	.40	4.2	Tr.	.....	.0	.....	.....	.8	4.0	56	8.9
Jan. 16	Jan. 25	10	7.0	.70	.....	16	.10	.....	1.2	.....	.0	39	.....	.1	3.0	62	6.8
Jan. 26	Feb. 4	35	24	.68	.....	30	.30	8.0	2.0	.....	.0	32	.....	.9	3.5	73	6.3
Feb. 5	Feb. 15	35	29	.83	.....	15	.30	8.8	2.0	.....	.0	30	.....	.1	3.3	51	9.3
Feb. 16	Feb. 26	60	48	.80	.....	17	.10	9.6	1.6	.....	.0	32	.....	.4	4.0	60	7.7
Feb. 27	Mar. 8	80	65	.81	.....	18	.20	8.4	Tr.	.....	.0	27	.....	.3	4.0	60	10.3
Mar. 10	Mar. 19	65	51	.78	.....	16	.10	.....	1.2	.....	.0	46	.....	.8	1.2	69	8.3
Mar. 20	Mar. 29	105	94	.90	.....	16	.20	9.2	.8	.....	.0	29	.....	.6	2.0	48	6.6
Mar. 30	Apr. 8	35	34	.97	.....	19	.20	10	1.2	.....	.0	34	.....	.5	3.5	68	6.1
Apr. 9	Apr. 18	15	14	.93	.....	23	.20	7.2	2.8	.....	.0	29	.....	.2	3.0	58	6.3
Apr. 19	Apr. 28	80	99	1.24	.....	29	.30	5.0	1.6	.....	.0	22	.....	.1	4.5	61	10.6
Apr. 29	May 9	75	84	1.12	.....	21	.20	5.5	.8	5.0	.0	22	Tr.	.2	4.0	48	8.5
May 10	May 19	140	94	.67	.....	26	[b]2.8	6.1	4.0	6.0	.0	47	2.0	.4	3.0	91	6.8
May 20	May 30	325	254	.78	.....	41	[b]3.2	7.3	2.8	.....	.0	43	4.3	.3	2.0	118	6.2
May 31	June 9	500	546	1.09	.....	19	[b]3.2	4.5	1.3	10	.0	35	5.6	.5	3.0	115	14.5
June 10	June 19	600	720	1.20	.....	25	[b]3.0	4.9	2.4	6.1	.0	37	6.6	.3	2.0	90	10.4
June 20	June 29	500	544	1.09	.....	31	[b]4.0	4.9	3.1	3.5	.0	35	1.8	.5	2.0	108	8.4
June 30	July 9	730	619	.85	.....	34	[b]4.0	6.3	2.3	6.3	.0	37	5.9	.2	3.0	106	9.3
July 10	July 19	566	494	.87	.....	31	[b]2.0	6.5	2.6	7.5	.0	41	5.4	.2	2.5	112	8.3
July 20	July 29	960	606	.63	9.6	19	.03	5.3	1.8	11	.0	40	4.3	.7	1.9	60	7.2
July 30	Aug. 9	960	606	.63	11	22	.40	5.8	1.4	11	.0	40	4.6	.7	1.7	68	6.6
Aug. 10	Aug. 20	475	421	.89	21	20	.07	5.6	1.4	8.7	.0	39	4.4	.5	1.4	63	7.3
Aug. 24	Sept. 3	525	406	.77	18	23	.06	5.0	1.4	11	.0	38	4.1	.6	2.2	64	6.9
Sept. 4	Sept. 14	400	231	.58	15	17	.04	5.5	2.3	8.8	.0	39	4.4	.3	2.2	60	5.3
Sept. 15	Sept. 24	350	284	.81	10	....	.04	8.0	4.4	12	.....	.....	5.4	Tr.	1.4	....	4.8
Sept. 25	Oct. 4	550	530	.96	24	31	Tr.	3.1	1.4	7.6	.0	26	4.6	.5	2.2	74	10.7
Oct. 15	Oct. 25	45	40	.89	2.2	33	.03	6.1	1.4	12	.0	43	4.3	Tr.	2.2	77	4.0
Mean		259	214	.79	.....	25	.28	6.3	1.8	8.4	.0	34	4.2	.4	2.8	73	.....
Per ct. of anhydrous residue		.....	.....	.....	.....	37.9	[c].6	9.5	2.7	12.7	25.4	....	6.4	.6	4.2	....	.....

[a] Analyses October 21, 1906, to May 9, 1907, by Jas. R. Evans; May 10 to July 19, 1907, by W. D. Collins; July 20 to October 25, 1907, by R. B. Dole, Chase Palmer, and W. D. Collins.

[b] Omitted from average.

[c] Fe_2O_3.

Mineral analyses of water from East Fork of White River near Azalia, Ind.[a]

[Parts per million, unless otherwise stated.]

Date (1906–7). From—	Date (1906–7). To—	Turbidity.	Suspended matter.	Coefficient of fineness.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.
Sept. 12	Sept. 23	25	22	0.88	29	Tr.	.....	.....	8.6	0.0	293	24	1.8	8.0	305
Sept. 24	Oct. 3	55	61	1.11	13	0.10	56	24	7.6	.0	268	30	2.2	5.5	264
Oct. 5	Oct. 15	25	29	1.16	18	.10	64	25	15	.0	290	26	3.9	3.7	290
Oct. 16	Oct. 25	10	14	1.40	9.6	Tr.	66	26	12	.0	300	25	.9	4.1	280
Oct. 26	Nov. 4	10	9.2	.92	13	Tr.	63	29	16	.0	319	35	.5	5.9	302
Nov. 5	Nov. 16	5	Tr.	.....	15	.05	70	28	13	.0	316	33	1.4	2.0	305
Nov. 17	Nov. 27	95	98	1.03	11	.30	53	18	12	.0	225	34	4.4	2.4	236
Nov. 28	Dec. 7	25	26	1.04	18	.05	67	24	.....	.0	307	40	9.7	2.7	311
Dec. 8	Dec. 18	40	39	.98	22	.10	62	20	13	.0	266	37	8.8	2.3	289
Dec. 19	Dec. 28	10	3.2	.32	13	.05	66	27	5.6	.0	303	33	9.7	.....	306
Dec. 29	Jan. 7	125	114	.91	21	1.2	42	.....	7.5	.0	176	28	4.4	1.3	196
Jan. 8	Jan. 17	70	32	.46	16	Tr.	45	15	4.8	.0	184	35	7.9	1.6	197
Jan. 18	Jan. 27	120	67	.56	16	.40	43	16	6.3	.0	177	23	7.0	2.0	196
Jan. 28	Feb. 7	5	Tr.	.....	22	Tr.	70	27	.....	.0	300	32	7.3	2.2	307
Feb. 8	Feb. 17	5	7.6	1.52	12	.10	79	26	.....	.0	320	39	9.2	2.7	312
Feb. 18	Feb. 27	5	2.0	.40	15	Tr.	68	28	11	.0	318	34	6.2	2.5	331
Feb. 28	Mar. 10	50	53	1.06	15	Tr.	60	22	9.4	.0	267	34	9.9	2.3	272
Mar. 11	Mar. 20	220	155	.70	21	.8	42	.....	11	.0	192	18	8.6	2.5	209
Mar. 21	Mar. 30	30	32	1.07	11	.15	64	21	7.9	.0	284	31	5.0	2.8	280
Mar. 31	Apr. 9	10	Tr.	.....	10	.10	60	22	5.6	.0	.....	30	8.8	2.0	269
Apr. 10	Apr. 19	3	Tr.	.....	11	.05	58	24	7.6	.0	279	33	12	2.3	283
Apr. 21	Apr. 29	20	31	1.55	6.6	.20	56	23	7.8	.0	246	36	9.6	2.4	261
Apr. 30	May 9	10	Tr.	.....	8.0	.01	59	24	6.7	.0	268	31	7.5	2.3	280
May 10	May 21	75	62	.83	6.8	.04	.....	24	6.2	.0	266	32	4.4	2.5	256
May 22	May 31	105	94	.90	9.0	.16	58	23	5.9	.0	258	33	6.0	2.2	269
June 1	June 11	245	240	.98	14	.25	54	17	5.9	.0	230	23	10	1.6	240
June 12	June 23	60	93	1.55	25	.20	64	19	5.2	.0	269	28	4.4	1.9	292
June 24	July 3	10	Tr.	.....	15	.01	66	24	7.3	.0	323	26	4.2	3.1	305
July 4	July 14	245	213	.87	13	.35	58	21	9.2	.0	263	26	6.0	1.6	256
July 15	July 24	75	78	1.04	15	.12	64	23	13	.0	300	27	7.8	2.0	303
July 25	Aug. 3	50	.....	.....	13	.08	67	.....	12	.0	304	28	4.9	2.5	297
Aug. 4	Aug. 13	10	47	4.70	13	.01	72	26	14	.0	316	35	1.6	3.8	334
Aug. 14	Aug. 24	10	14	1.40	18	Tr.	.....	25	.....	.0	316	31	1.1	.....	329
Aug. 25	Sept. 3	10	28	2.80	12	.10	65	25	9.2	.0	308	29	2.2	4.0	291
Sept. 4	Sept. 13	5	Tr.	.....	14	.01	64	25	13	.0	320	29	2.6	5.3	300
Sept. 14	Sept. 23	30	30	1.00	16	Tr.	67	22	11	[b]8.4	261	26	2.2	6.0	286
Sept. 24	Oct. 3	25	26	1.04	21	Tr.	66	22	12	[b]12	259	28	1.7	6.2	292
Mean		52	48	1.18	15	.14	61	23	9.5	.0	276	30	5.6	3.1	279
Per ct. of anhydrous residue		.....	.....	.....	5.3	[c].1	21.5	8.1	3.3	48.0	.....	10.6	2.0	1.1	....

[a] Analyses September 12, 1906, to February 17, 1907, by W. M. Barr; February 18 to 27, 1907, by H. S. Spaulding; February 28 to September 13, 1907, by Walton Van Winkle; September 14 to October 3, 1907, by R. B. Dole, Chase Palmer, and W. D. Collins.

[b] Abnormal; computed as HCO_3 in the average.

[c] Fe_2O_3.

Mineral analyses of water from West Fork of White River near Indianapolis, Ind.[a]

[Parts per million, unless otherwise stated.]

Date (1906–7).		Turbidity.	Suspended matter.	Coefficient of fineness.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.
From—	To—														
Sept. 8	Sept. 18	25	18	0.72	27	0.10	81	36	78	0.0	301	67	1.7	145	590
Sept. 19	Sept. 28	20	12	.60	20	Tr.	83	43	127	.0	303	78	.5	262	793
Sept. 29	Oct. 8	25	13	.52	22	.7	78	37	91	[b]6.5	280	74	.9	195	668
Oct. 9	Oct. 19	15	5.6	.37	11	.10	84	37	109	.0	293	73	1.1	215	701
Oct. 20	Oct. 31	10	5.2	.52	8.4	.10	93	.....	138	.0	331	125	.7	207	705
Nov. 1	Nov. 11	10	11	1.10	19	Tr.	95	38	129	.0	344	75	1.3	251	798
Nov. 12	Nov. 21	10	8.8	.88	14	.20	95	36	123	.0	353	79	2.2	216	754
Nov. 23	Dec. 2	40	28	.70	18	Tr.	73	27	44	.0	266	78	13	63	448
Dec. 3	Dec. 12	30	21	.70	22	.13	77	34	47	.0	287	85	9.7	72	474
Dec. 13	Dec. 22	30	29	.97	20	.20	71	33	26	.0	254	76	13	38	382
Dec. 23	Jan. 4	40	27	.68	16	.8	79	28	34	.0	290	68	8.8	55	412
Jan. 5	Jan. 14	125	96	.77	13	.5	50	.....	14	.0	205	41	14	14	249
Jan. 15	Jan. 25	125	101	.81	18	.6	48	17	20	.0	.....	36	9.5	13	245
Jan. 26	Feb. 4	20	25	1.25	12	.10	79	26	20	.0	293	56	6.3	35	378
Feb. 5	Feb. 14	10	4.8	.48	10	.10	86	32	38	.0	349	61	7.6	52	451
Feb. 16	Feb. 25	Tr.	Tr.	.....	10	.10	82	29	38	.0	311	60	9.7	60	441
Feb. 26	Mar. 7	5	.....	.....	15	.08	79	31	49	.0	314	52	5.9	65	454
Mar. 8	Mar. 17	235	124	.53	9.0	.20	62	23	26	.0	.....	38	9.7	30	305
Mar. 18	Mar. 27	35	30	.86	16	Tr.	64	24	21	.0	262	42	4.7	26	339
Mar. 28	Apr. 7	10	.....	.....	7.0	.10	66	24	32	.0	266	47	10	46	351
Apr. 8	Apr. 17	5	Tr.	.....	12	.18	75	27	36	.0	281	55	5.8	62	422
Apr. 18	Apr. 27	5	Tr.	.....	8.8	.20	65	30	41	.0	273	60	4.8	67	414
Apr. 29	May 8	10	34	3.40	8.8	.05	69	30	34	.0	280	59	6.2	57	425
May 9	May 19	10	.....	.....	10	.02	72	29	35	.0	282	48	4.1	57	416
May 20	May 30	20	50	2.50	6.8	.02	74	27	35	.0	282	58	8.3	70	415
June 1	June 10	80	52	.65	9.6	.01	61	22	18	.0	236	44	5.6	33	343
June 11	June 20	50	71	1.42	23	.05	67	21	14	.0	260	42	3.4	21	332
June 21	June 30	25	.....	.....	16	.06	69	26	.....	.0	298	45	7.9	34	365
July 1	July 11	50	36	.72	13	.10	70	27	29	.0	298	49	7.1	43	380
July 13	July 22	130	122	.94	14	.05	66	19	17	.0	259	20	6.0	15	300
July 23	Aug 2	80	111	1.39	9.0	.01	72	22	26	.0	305	40	6.6	27	357
Aug. 3	Aug. 13	30	72	2.40	15	Tr.	74	28	31	.0	312	45	7.3	38	415
Aug. 14	Aug. 23	20	26	1.30	11	.02	77	30	42	.0	326	51	4.9	50	430
Aug. 24	Sept. 3	20	17	.85	12	.30	70	29	42	.0	295	58	1.3	54	408
Sept. 4	Sept. 12	10	.....	.....	15	.08	75	22	37	.0	298	47	4.8	42	396
Mean		39	38	1.04	14	.15	74	29	48	.0	291	58	6.1	78	450
Per ct. of anhydrous residue		.....	.....	.....	3.1	[c]0	16.4	6.4	10.7	31.8	.....	12.9	1.4	17.3	....

[a] Analyses September 8, 1906, to February 14, 1907, by W. M. Barr; February 16 to 25, 1907, by H. S. Spaulding; February 26 to September 12, 1907, by Walton Van Winkle.

[b] Abnormal; computed as HCO_3 in the average.

[c] Fe_2O_3.

Mineral analyses of water from Wisconsin River near Portage, Wis.[a]

[Parts per million unless otherwise stated.]

Date. (1906–7). From	To—	Turbidity.	Suspended matter.	Coefficient of fineness.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.	Mean gage height (feet).[b]
Sept. 11	Sept. 20	10	7.6	0.76	26	0.25	14	7.3	9.2	0.0	66	.....	1.3	0.8	117	5.2
Sept. 21	Sept. 30	15	9.6	.64	16	.40	14	7.2	.....	.0	68	13	.9	2.5	109	5.3
Oct. 1	Oct. 11	10	4.0	.40	13	Tr.	16	8.5	7.8	.0	66	13	.5	1.5	105	4.8
Oct. 12	Oct. 22	5	5.6	1.12	15	.30	16	8.3	10	.0	75	16	.5	1.0	98	4.9
Oct. 23	Oct. 31	5	9.2	1.84	19	Tr.	16	8.9	7.6	.0	60	24	Tr.	4.0	108	6.5
Nov. 1	Nov. 10	5	5.6	1.12	17	Tr.	15	7.3	7.1	.0	51	15	Tr.	2.5	100	6.1
Nov. 11	Nov. 21	10	6.0	.60	6.6	.10	14	6.2	7.8	.0	49	11	.4	1.5	100	5.7
Nov. 22	Dec. 1	10	4.0	.40	6.4	.10	13	5.4	7.6	.0	48	14	.4	6.0	93	6.8
Dec. 2	Dec. 11	10	10	1.00	16	.30	.....	4.9	9.7	.0	43	19	1.3	1.3	89	6.8
Dec. 12	Dec. 22	10	5.6	.56	22	.40	13	7.4	11	.0	59	19	.4	3.2	112	6.5
Dec. 23	Jan. 1	5	2.0	.40	15	.40	14	6.8	.....	.0	48	25	Tr.	.9	105	....
Jan. 2	Jan. 11	5	Tr.	.....	16	.40	15	7.6	7.8	.0	72	19	.4	1.8	106	....
Jan. 12	Jan. 22	5	1.6	.32	15	.20	.....	7.2	7.3	.0	72	23	1.4	2.8	102	....
Jan. 23	Feb. 1	5	Tr.	.....	13	.25	16	9.6	5.9	.0	71	.....	Tr.	1.8	105	....
Feb. 2	Feb. 12	5	9.2	1.84	13	.40	18	6.7	13	.0	76	25	2.4	.....	108	....
Feb. 13	Feb. 23	5	2.0	.40	13	.20	.....	7.6	10	.0	72	15	2.2	4.5	98	....
Feb. 24	Mar. 6	5	Tr.	.....	11	.18	17	8.3	12	.0	75	23	1.6	2.1	109	....
Mar. 7	Mar. 17	10	10	1.00	10	.23	15	.....	11	.0	73	.....	1.9	1.8	107	6.4
Mar. 18	Mar. 28	10	14	1.40	9.0	.20	11	7.2	5.1	.0	47	13	1.9	1.8	78	7.7
Mar. 29	Apr. 7	5	Tr.	.....	5.8	.20	9.2	2.8	4.3	.0	26	11	1.7	1.2	65	12.3
Apr. 8	Apr. 17	10	.....	.....	18	.15	11	4.8	.....	.0	49	21	1.0	.6	96	9.2
Apr. 18	Apr. 27	5	Tr.	.....	11	.20	10	4.9	5.9	.0	37	16	.5	1.9	78	7.8
Apr. 28	May 7	5	Tr.	.....	7.6	.25	11	5.0	5.7	.0	35	17	Tr.	.....	87	7.9
May 8	May 17	Tr.	Tr.	.....	6.8	.20	.....	5.5	4.6	.0	43	11	Tr.	1.5	88	7.2
Mean		7	4.6	.86	13	.22	14	6.8	8.1	.0	58	17	.9	2.1	98	....
Per ct. of anhydrous residue		....	.....	.....	14.3	c.3	15.4	7.5	8.9	31.5	.....	18.8	1.0	2.3	.....	....

[a] Analyses September 11, 1906, to February 12, 1907, by W. M. Barr; February 13 to March 6, 1907, by H. S. Spaulding; March 7 to May 17, 1907, by Walton Van Winkle.

[b] Gaging station at Necedah, Wis., 50 miles below.

[c] Fe_2O_3.

Mineral analyses of water from Youghiogheny River near McKeesport, Pa.[a]

[Parts per million unless otherwise stated.]

Date. (1906-7). From—	To—	Turbidity.	Suspended matter.	Coefficient of fineness.	Total iron (Fe).	Silica (SiO_2).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K)	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.	Acidity as H_2SO_4.	Mean gage height (feet).[b]
Sept. 6	Sept. 16	4	.....	.....	.....	11	6.7	.....	37	14	13	0.0	0.0	.....	Tr.	5.5	397	72	0.06
Sept. 17	Sept. 26	22	18	0.82	7.6	12	5.8	.....	52	17	21	.0	.0	300	Tr.	6.0	453	75	.....
Sept. 27	Oct. 6	5	11	2.20	8.4	10	7.0	.....	42	16	16	.0	.0	245	0.0	5.0	374	66	.06
Oct. 7	Oct. 16	3	4	1.33	4.5	8.2	.5	5.0	29	8.4	12	.0	.0	172	.7	4.8	298	34	.65
Oct. 17	Oct. 26	8	10	1.25	3.3	8.4	.4	6.0	29	5.6	10	.0	.0	167	.8	5.8	249	20	.52
Oct. 27	Nov. 5	11	14	1.28	6.5	9.0	.5	7.2	29	5.6	12	.0	.0	174	.4	5.4	251	30	.21
Nov. 6	Nov. 15	8	19	2.38	9.9	7.8	.8	.....	34	5.8	14	.0	.0	227	.6	5.7	311	53	.05
Nov. 16	Nov. 25	140	172	1.23	20	5.6	.2	4.0	22	3.2	8.8	.0	.0	127	.8	4.6	184	22	2.04
Nov. 26	Dec. 5	49	32	.65	5.7	5.6	.07	.....	15	4.0	10	.0	.0	97	.8	3.4	118	16	1.25
Dec. 6	Dec. 16	190	443	2.33	19	5.2	.09	0.8	12	4.2	3.9	.0	c3.9	40	2.8	3.8	84	.0	4.50
Dec. 17	Dec. 27	50	39	.78	3.5	3.8	.12	2.6	14	4.8	4.4	.0	.0	73	2.8	3.8	119	10	3.41
Dec. 28	Jan. 7	190	238	1.25	17	7.8	.07	3.4	17	5.4	4.1	.0	.0	85	2.1	3.7	138	10	5.31
Jan. 8	Jan. 17	230	274	1.19	12	6.0	.06	2.0	14	4.2	.....	.0	c5.1	62	2.1	3.1	103	.0	8.20
Jan. 18	Jan. 26	210	500	2.38	20	8.6	.06	5.6	20	5.6	5.7	.0	.0	104	1.9	3.6	164	10	7.60
Jan. 29	Feb. 7	47	39	.84	7.2	8.6	.35	8.2	23	7.5	6.9	.0	.0	141	2.0	4.8	226	33	3.70
Feb. 8	Feb. 17	43	54	1.26	8.6	8.2	.2	8.8	23	7.2	6.6	.0	.0	142	1.9	4.0	224	30	2.62
Feb. 18	Feb. 27	55	35	.64	8.8	7.2	.13	5.8	18	5.8	5.0	.0	.0	107	2.0	3.8	171	20	4.26
Feb. 28	Mar. 9	80	47	.59	13	6.4	.15	3.7	.....	3.8	2.7	.0	.0	82	.5	3.8	127	15	3.21
Mar. 10	Mar. 22	1,600	1,580	.99	135	8.8	.10	2.3	.....	5.2	5.5	.0	c7.5	86	1.6	2.6	140	.0	10.34
Mar. 23	Apr. 1	140	55	.39	18	11	.18	10	28	7.6	7.7	.0	.0	165	1.6	3.0	239	22	3.43
Apr. 2	Apr. 14	110	62	.56	26	11	.15	11	30	8.6	11	.0	.0	184	.6	5.0	277	66	2.00
Apr. 15	Apr. 24	240	178	.74	47	16	.07	2.8	17	5.2	7.6	.0	.0	86	1.3	4.2	140	17	3.26
Apr. 25	May 4	82	49	.60	12	7.6	.05	2.2	16	4.6	7.9	.0	.0	74	1.1	2.4	123	11	3.16
May 5	May 15	540	640	1.18	70	14	.06	0.5	20	6.4	8.2	.0	c7.3	78	1.1	5.0	143	.0	3.85
May 16	May 25	45	33	.73	12	8.4	.06	4.2	19	6.2	9.1	.0	.0	104	.7	4.2	157	11	2.37
May 26	June 4	160	103	.64	18	7.2	.05	2.2	16	5.2	7.2	.0	.0	74	.7	3.0	118	6.9	3.26
June 5	June 14	290	450	1.55	32	8.2	.03	0.7	13	3.6	9.1	.0	c6.1	54	1.1	2.4	98	.0	4.37
June 15	June 24	60	68	1.14	8.8	8.4	.04	2.2	17	5.2	8.8	.0	.0	80	1.1	4.2	129	3.4	3.09
June 25	July 4	7	21	3.00	6.0	7.8	.04	2.4	24	6.8	11	.0	.0	116	.7	6.6	181	22	1.36
July 5	July 14	52	67	1.29	16	9.4	.09	2.8	30	8.2	13	.0	.0	152	.6	5.8	236	28	1.51
July 16	July 26	46	51	1.11	3.2	6.8	.05	.....	14	3.8	14	.0	cTr.	66	1.3	4.8	112	.0	2.67
July 27	Aug. 5	106	118	1.12	9.8	6.8	.04	1.3	16	4.2	7.9	.0	.0	76	1.2	3.2	120	3.9	2.16
Aug. 6	Aug. 15	31	33	1.06	4.2	7.8	.03	2.1	24	7.0	10	.0	.0	116	.7	4.8	183	14	1.35

Aug. 16	Aug. 26	15	20	1.33	3.7	8.4	.1	3.6	30	8.8	12	.0	.0	160	.6	7.4	255	24	1.18
Aug. 27	Sept. 6	55	53	.96	5.6	10	.05	3.3	30	8.2	11	.0	.0	153	1.1	8.4	242	16	.90
Mean		141	163	1.20	18	8.5	.70	4.0	23	6.7	9.3	.0	.0	123	1.1	4.5	197	22	.....
Per ct. of anhydrous residue		.....	.....	.....	.....	4.7	[d]4	2.2	12.7	3.7	5.2	.0	.....	68.0	3.6	2.5	.....	.....	.....

[a] Analyses September 6 to November 5, 1906, by R. B. Dole; November 6, 1906, to April 1, 1907, by R. B. Dole and M. G. Roberts; April 2 to September 6, 1907, by Chase Palmer and M. G. Roberts.

[b] Gaging station at West Newton, Pa., 10 miles above.

[c] Omitted from the average.

[d] $Fe_2O_3+Al_2O_3$.

Summary of results of mineral analyses of surface waters for eastern United States.

Source of sample (river, except as noted).	Average mineralization (parts per million).														Chemical composition of mineral matter (per cent of anhydrous residue[a]).								
	Turbidity.	Suspended matter.	Coefficient of fineness.	Total iron (Fe).	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.	Silica (SiO_2).	Oxide of iron (Fe_2O_3).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).
Alabama, Selma, Ala	141	100	0.72	.....	21	0.53	13	2.9	7.0	0.0	48	9.0	0.7	2.3	82	26.2	0.9	16.2	3.6	8.7	29.4	11.2	0.9	2.9
Allegheny, Kittanning, Pa	21	30	1.14	1.2	7.9	.13	14	3.0	11	.0	38	17	.7	14	87	9.1	.2	16.1	3.5	12.7	21.9	19.6	.8	16.1
Androscoggin, Brunswick, Me.[a]	.....	.....	.....	.....	9.0	[b]3.2	7.4	1.1	3.5	.....	.....	12	.....	2.3	42	18.6	[b]6.6	15.3	2.3	7.3	20.3	24.8	.....	4.8
Arkansas, Little Rock, Ark	755	748	.88	.....	28	.82	55	13	144	.0	148	93	2.0	203	630	4.6	.2	9.0	2.1	23.5	11.9	15.2	.3	33.2
Big Muddy, Murphysboro, Ill	245	129	.5	.....	24	2.1	25	12	20	.....	72	72	2.0	13	225	11.6	1.0	12.2	5.7	10.0	17.2	35.1	1.0	6.2
Big Vermilion, Danville, Ill	115	82	.8	.....	14	.29	54	25	13	.....	243	42	12	4.5	281	4.9	.1	19.0	8.8	4.6	42.1	14.7	4.2	1.6
Brazos, Waco, Tex	1,462	488	1.03	.....	22	.26	121	19	234	.0	158	279	2.2	338	1,136	2.0	.0	11.1	1.7	21.4	7.1	25.5	.2	31.0
Cache, Mounds, Ill	134	66	.6	.....	22	2.5	19	6.0	15	.....	85	19	2.1	6.8	149	16.4	1.9	14	4.4	11	30.7	14	1.5	5.0
Cahaba, Birmingham, Ala	40	32	.81	.....	16	.44	13	2.5	9.1	.0	52	8.8	.6	2.2	76	20.4	.8	16.6	3.2	11.6	32.7	11.2	.7	2.8
Cape Fear, Wilmington, N. C	73	21	.92	1.3	9.9	.78	5.0	1.5	7.2	.0	25	3.2	.2	5.8	57	21.6	2.4	10.9	3.3	15.7	26.1	7.0	.4	12.6
Cedar, Cedar Rapids, Iowa	64	61	.97	.....	14	.09	48	16	12	.0	209	30	3.1	3.4	228	6.1	.1	20.9	7.0	5.2	44.8	13.0	1.4	1.5
Chattahoochee, West Point, Ga	185	136	.71	.....	20	.47	4.8	.8	7.7	.0	23	4.5	.7	2.1	52	38.0	1.3	9.1	1.6	14.6	21.5	8.5	1.4	4.0
Chippewa, Eau Claire, Wis	7.0	3.7	.97	.....	12	.22	13	4.7	8.1	.0	48	14	.6	1.1	90	15.5	.4	16.8	6.1	10.5	30.5	18.0	.8	1.4
Colorado, Austin, Tex	.....	351	.....	.....	18	3.1	52	17	49	.0	195	42	.....	59	321	5.4	.9	15.5	5.1	14.6	28.5	12.5	.....	17.5
Cumberland:																								
Nashville, Tenn	126	94	.74	.....	20	.42	26	3.6	9.6	.0	92	14	1.2	2.1	119	16.4	.5	21.3	2.9	7.8	37.0	11.4	1.0	1.7
Kuttawa, Ky	176	165	.92	.....	18	.30	28	4.3	7.8	.9	100	9.7	1.8	3.0	124	14.6	.4	22.8	3.5	6.3	40.6	7.9	1.5	2.4
Dan, South Boston, Va	132	264	2.35	7.5	24	1.1	5.6	1.5	6.8	.0	33	3.4	1.1	3.2	71	38.0	2.5	8.9	2.4	10.7	25.3	5.4	1.7	5.1
Delaware, Lambertville, N. J	16	26	1.74	.6	9.0	.07	12	3.3	5.4	.0	46	12	1.1	2.9	70	13.1	.2	17.5	4.8	7.9	33.2	17.5	1.6	4.2
Des Moines, Keosauqua, Iowa	542	642	1.09	.....	22	.36	58	21	17	.0	216	71	3.3	4.8	312	7.2	.2	19.0	6.9	5.6	35.0	23.4	1.1	1.6
Embarrass:																								
Charleston, Ill	155	140	.9	.....	17	.34	51	24	13	.....	249	31	7.6	4.9	270	6.3	.2	18.8	8.9	4.8	45	11.4	2.8	1.8
Lawrenceville, Ill	118	66	.7	.....	17	.53	44	19	28	.....	195	35	3.7	35	283	6.1	.3	15.8	6.8	10.0	34.5	12.6	1.3	12.6
Erie, Lake, Buffalo, N. Y	41	Tr.	.....	.....	5.9	.07	31	7.6	6.5	3.1	114	13	.3	8.7	133	4.5	.1	23.4	5.7	4.9	44.8	9.8	.2	6.6
Flint, Albany, Ga	100	58	.67	.....	24	.86	8.8	1.4	[a]7.0	.0	31	[c]6.0	.6	2.8	67	35.8	[b]1.8	13.0	2.1	10.4	22.8	9.0	.9	4.2
Fox:																								
Elgin, Ill	34	23	.7	.....	12	.15	51	30	11	.....	268	38	2.4	5.2	290	4.3	.1	18.1	10.6	3.9	46.8	13.5	.9	1.8
Ottawa, Ill	94	87	1.2	.....	11	.20	60	32	14	.....	275	61	4.9	7.9	335	3.4	.1	18.4	9.8	4.3	41.4	18.7	1.5	2.4
Grand, Grand Rapids, Mich	37	43	1.61	1.1	14	.07	56	19	10	8.5	214	33	2.3	7.7	258	5.5	.0	21.9	7.4	3.9	44.5	12.9	.9	3.0
Hudson, Hudson, N. Y	13	16	1.26	.7	11	.15	21	3.8	7.9	.0	73	16	.8	4.0	108	10.9	.2	20.9	3.8	7.8	35.7	15.9	.8	4.0
Huron, Lake, Port Huron, Mich	Tr.	Tr.	.....	.....	12	.04	24	7.0	4.4	1.8	100	6.2	.4	2.6	108	11.1	.0	22.3	6.5	4.1	47.4	5.8	.4	2.4

Illinois:																								
La Salle, Ill.	159	136	.8	.....	12	.21	50	22	16	.....	203	50	6.6	13	278	4.5	.1	18.6	8.1	5.9	37.0	18.6	2.4	4.8
Peoria, Ill.	43	26	.8	.....	12	.21	49	21	17	.....	198	48	7.8	13	271	4.5	.1	18.5	7.9	6.4	36.7	18.1	2.9	4.9
Kampsville, Ill.	188	145	.8	.....	12	.27	47	20	18	.....	202	42	4.3	15	267	4.6	.1	18.2	7.8	7.0	38.5	16.3	1.7	5.8
Iowa, Iowa City, Iowa	168	120	.80	.....	19	.25	49	17	14	.0	210	36	2.8	3.6	247	7.8	.1	20.0	6.9	5.7	42.2	14.7	1.1	1.5
James, Richmond, Va.	90	71	.96	3.9	18	.5	14	3.0	6.7	.0	60	7.1	.3	2.3	89	22.0	.9	17.1	3.7	8.2	36.2	8.7	.4	2.8
Kalamazoo, Kalamazoo, Mich.	7	19	2.64	.2	17	.05	55	18	8.2	7.8	216	2.3	1.9	3.4	242	7.1	.0	22.9	7.5	3.4	47.3	9.6	.8	1.4
Kankakee, Kankakee, Ill.	50	32	.7	.....	15	.27	58	21	12	.....	215	57	4.1	4.9	288	5.4	.1	20.8	7.5	4.3	38.1	20.5	1.5	1.8
Kaskaskia:																								
Carlisle, Ill.	184	126	.7	.....	17	.39	47	20	14	.....	213	34	4.8	6.9	248	6.8	.2	18.9	8.0	5.6	42.1	13.7	1.9	2.8
Shelbyville, Ill.	110	84	.9	.....	16	.23	53	26	13	.....	262	34	6.9	5.6	279	5.6	.1	18.7	9.2	4.6	45.4	12.0	2.4	2.0
Kentucky, Frankfort, Ky.	150	142	.93	4.7	16	.49	21	3.7	6.8	2.4	73	8.3	2.5	2.0	104	16.1	.7	21.1	3.7	6.9	38.6	8.4	2.5	2.0
Lehigh, South Bethlehem, Pa.	14	21	2.46	1.2	8.8	.10	14	5.7	7.5	.0	40	30	2.2	4.9	95	9.5	.1	15.0	6.1	8.1	21.2	32.3	2.4	5.3
Little Vermilion, Streator, Ill.	107	78	.7	.....	14	.22	55	29	18	.....	241	68	12	6.9	325	4.4	.1	17.1	9.0	5.6	36.9	21.1	3.7	2.1
Little Wabash, Carmi, Ill.	135	68	.5	.....	26	2.0	20	9.1	15	.....	88	32	2.1	7.5	176	16.6	1.3	12.7	5.8	9.5	27.6	20.4	1.3	4.8
Maumee, Toledo, Ohio	143	112	.95	3.4	17	.27	57	16	24	2.5	173	48	4.5	40	298	5.8	.1	19.4	5.4	8.2	29.7	16.3	1.5	13.6
Miami, Dayton, Ohio	84	94	1.46	2.0	17	.15	59	24	9.0	5.8	244	40	8.6	4.1	289	5.9	.1	20.5	8.3	3.1	43.8	13.9	3.0	1.4
Michigan, Lake, St. Ignace, Mich.	Tr.	Tr.	.....	.....	10	.04	26	8.2	4.7	2.9	112	7.2	.3	2.7	118	8.5	.0	22.2	7.0	4.0	49.6	6.1	.3	2.3
Minnesota, Shakopee, Minn.	97	142	1.18	.....	23	.09	82	35	23	.0	296	144	2.0	4.7	486	5.0	.0	17.9	7.6	5.0	31.7	31.4	.4	1.0
Mississippi:																								
Minneapolis, Minn.	10	7.9	1.13	.....	15	.07	40	14	10	.0	188	18	1.4	1.6	200	7.8	.1	20.8	7.3	5.2	48.0	9.3	.7	.8
Moline, Ill.	117	106	.9	.....	16	.39	33	13	10	.....	152	24	1.8	3.7	179	9.0	.3	18.7	7.3	5.7	42.3	13.6	1.0	2.1
Quincy, Ill.	173	119	.8	.....	18	.46	36	16	11	.....	175	25	2.2	4.4	203	8.8	.3	19.1	7.7	5.2	42.9	12.9	1.2	1.9
Chester, Ill.	858	634	.8	.....	22	.39	44	16	21	.....	174	56	2.7	9.8	269	8.5	.2	17.1	6.2	8.2	33.2	21.8	1.0	3.8
Memphis, Tenn.	556	519	.97	.....	24	.61	36	12	19	.0	129	43	1.7	8.6	202	11.5	.4	17.3	5.7	9.1	30.5	20.6	.8	4.1
New Orleans, La.	.....	.....	.....	.....	11	[b].53	32	8.4	13	.0	111	24	2.5	9.7	166	7.1	[a].6	20.6	5.4	8.4	34.7	15.4	1.6	6.2
Missouri:																								
Florence, Nebr.	1,726	2,059	1.16	.....	31	.44	65	20	49	.0	203	168	1.8	8.9	454	7.0	.2	14.6	4.5	11.0	22.5	37.8	.4	2.0
Kansas City, Kans.	1,909	2,032	1.04	.....	37	.73	62	18	44	.0	202	135	2.2	13	426	9.0	.2	15	4.4	10.7	24.2	32.8	.5	3.2
Ruegg, Mo.	1,931	1,890	1.02	.....	29	.51	52	16	36	.0	178	104	2.9	12	346	8.5	.2	15.3	4.7	10.6	25	30.6	.8	3.5
Monongahela, Elizabeth, Pa.	82	84	1.11	3.7	8.4	.49	12	2.2	7.3	.0	18	33	1.8	3.2	81	10.8	.9	15.5	2.8	9.4	11.5	42.6	2.3	4.2
Muskingum, Zanesville, Ohio	96	70	1.71	3.2	14	.18	43	9.5	23	1.3	115	43	1.6	40	244	6.0	.1	18.5	4.1	9.9	25.0	18.5	.7	17.2
Neuse, Raleigh, N. C.	78	68	.79	2.8	26	1.4	5.9	1.8	7.9	.0	35	3.4	.3	4.4	73	37.7	2.9	8.6	2.6	11.5	25.0	4.9	.4	6.4
North Platte, North Platte, Nebr.	307	311	.95	.....	40	.26	46	12	32	.0	165	76	1.2	6.9	295	13.5	.1	15.6	4.1	10.8	27.5	25.7	.4	2.3
Oconee, Dublin, Ga.	208	171	.78	.....	21	.68	8.5	1.6	8.8	.0	37	6.2	1.0	3.4	68	30.2	1.4	12.2	2.3	12.6	26.1	8.9	1.4	4.9
Ocmulgee, Macon, Ga.	230	174	.72	.....	26	.9	6.3	1.2	8.3	.0	28	4.9	.7	2.8	69	39.8	2.0	9.6	1.8	12.7	21.2	7.5	1.1	4.3
Oostanaula, Rome, Ga.	128	109	.80	.....	24	.7	12	2.6	9.2	.0	53	4.1	.4	1.8	82	29.6	1.2	14.8	3.2	11.3	32.2	5.0	.5	2.2
Oswegatchie, Ogdensburg, N. Y.	8	10	1.38	.7	9.4	.21	13	3.5	5.3	.0	53	8.2	.4	.4	77	14.1	.4	19.5	5.3	8.0	39.2	12.3	.6	.6
Pearl, Jackson, Miss.	56	46	.93	.....	18	.37	7.1	1.1	8.9	.0	32	6.4	.7	3.4	59	29.1	.8	11.5	1.8	14.4	25.5	10.3	1.1	5.5
Pedee, Peedee, N. C.	131	94	.76	.....	26	.31	6.9	1.3	8.9	.0	32	4.0	.6	3.1	69	38.8	.7	10.3	1.9	13.3	23.6	6.0	.8	4.6
Platte:																								
Columbus, Nebr.	374	300	.81	.....	32	.20	63	18	48	.0	186	152	1.3	14	437	7.6	.1	15.0	4.3	11.4	21.8	36.2	.3	3.8
Fremont, Nebr.	379	392	1.03	.....	47	.26	47	11	30	.0	178	66	1.0	6.4	302	15.9	.1	15.9	3.7	10.1	29.6	22.3	.3	2.1
Potomac, Cumberland, Md.	28	29	1.59	3.0	8.2	.14	24	4.6	9.0	.0	36	58	.9	6.4	130	6.4	.2	18.6	3.5	7.0	13.7	45.0	.7	4.9
Raritan, Boundbrook, N. J.	37	36	1.16	1.2	16	.15	12	3.9	9.1	.0	51	12	1.9	4.7	85	18.8	.3	14.1	4.6	10.7	29.6	14.1	2.3	5.5
Red, Shreveport, La.	790	870	1.11	.....	30	1.1	74	17	90	4.6	135	140	.4	121	561	5.5	.3	13.6	3.1	16.5	13.1	25.7	.0	22.2

[a] Based on the assumption for anhydrous residue that the average content of bicarbonates is 20 parts. [b] $Fe_2O_3 + Al_2O_3$. [c] Approximate.

Summary of results of mineral analyses of surface waters for eastern United States—Continued.

Source of sample (river, except as noted).	Average mineralization (parts per million).														Chemical composition of mineral matter (per cent of anhydrous residue).								
	Turbidity.	Suspended matter.	Coefficient of fineness.	Total iron (Fe).	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.	Silica (SiO_2).	Oxide of iron (Fe_2O_3).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).
Reservoir:																								
Cartter, Ill	72	33	.5	.....	16	1.9	9.0	3.6	8.6	.....	34	16	2.1	5.2	92	20.3	2.4	11.4	4.6	10.9	21.0	20.2	2.6	6.6
Cypress, Ill	155	59	.5	.....	29	3.7	18	7.0	13	.....	67	33	2.2	6.8	165	19.9	2.5	12.4	4.8	8.9	22.6	22.7	1.5	4.7
Joppa, Ill	116	66	.5	.....	22	3.5	10	4.0	9.0	.....	43	19	1.9	4.3	111	23.2	3.7	10.5	4.2	9.5	22.4	20.1	2.0	4.4
Marion, Ill	97	43	.5	.....	13	.93	15	8.2	17	.....	51	45	1.7	8.3	140	9.7	.7	11.2	6.1	12.6	18.7	33.5	1.3	6.2
Rio Grande, Laredo, Tex	2,475	.....	.....	.....	29	3.6	104	23	119	.0	178	228	.....	164	791	3.8	.5	13.7	3.0	15.7	11.6	30.1	.....	21.6
Roanoke, Randolph, Va	169	127	.....	7.7	21	.95	9.5	3.5	5.9	.0	53	4.4	.5	2.2	79	28.2	1.8	12.8	4.7	7.9	35.1	5.9	.7	3.0
Rock:																								
Rockford, Ill	134	92	.7	.....	15	.44	45	25	10	.....	252	22	4.1	4.6	250	6.0	.2	18.0	10.0	4.0	49.6	8.8	1.6	1.8
Sterling, Ill	229	236	1.2	.....	15	.31	49	27	12	.....	263	25	3.8	5.5	267	5.6	.2	18.3	10.1	4.5	48.4	9.4	1.4	2.1
St. Lawrence, Ogdensburg, N. Y	4.5	Tr.	.....	.....	6.6	.05	31	7.2	6.3	2.9	116	12	.3	7.7	134	5.0	.1	23.6	5.5	4.8	45.7	9.2	.2	5.9
Saluda, Columbia, S. C	72	54	.71	.....	21	.38	8.4	1.3	[a]6.0	.0	33	[a]5.0	.43	3.5	62	33.6	.9	13.5	2.1	9.6	26.0	8.0	.7	5.6
Sangamon:																								
Decatur, Ill	126	87	.7	.....	19	.27	55	26	14	.....	268	35	8.5	5.4	293	6.4	.1	18.7	8.8	4.7	44.7	11.9	2.9	1.8
Springfield, Ill	74	39	.8	.....	16	.32	52	24	16	.....	247	37	3.4	7.5	276	5.8	.1	18.7	8.6	5.8	43.8	13.3	1.2	2.7
Chandlerville, Ill	154	102	.7	.....	15	.32	52	25	15	.....	255	36	6.1	7.6	282	5.3	.1	18.4	8.8	5.3	44.4	12.8	2.2	2.7
Savannah, Augusta, Ga	172	142	.77	.....	23	.44	5.7	.8	12	.0	30	6.0	.6	2.1	60	35.0	.9	8.7	1.2	18.3	22.6	9.1	1.0	3.2
Shenandoah, Millville, W. Va	31	39	1.64	.9	15	.08	32	8.2	6.7	1.3	132	6.2	2.6	3.0	140	10.7	.1	22.8	5.9	4.8	47.3	4.4	1.9	2.1
Superior, Lake, Sault Ste. Marie, Mich	2	Tr.	.....	.....	7.4	.06	13	3.1	3.2	.0	56	2.1	.5	1.1	60	12.7	.2	22.4	5.3	5.5	47.5	3.6	.9	1.9
Susquehanna:																								
West Pittston, Pa	14	22	4.00	1.0	10	.12	18	3.4	6.3	.0	63	14	1.5	4.2	90	11.3	.2	20.4	3.8	7.1	35.0	15.8	1.7	4.7
Williamsport, Pa	10	18	2.23	.9	7.6	.11	12	3.4	6.0	.0	28	26	.7	4.0	74	10.3	.2	16.3	4.6	8.1	18.8	35.3	1.0	5.4
Danville, Pa	16	21	1.73	.8	8.7	.09	21	4.6	8.9	.0	54	31	3.4	8.1	112	7.7	.1	18.7	4.1	7.9	23.7	27.6	3.0	7.2
Tennessee:																								
Knoxville, Tenn	204	156	.81	.....	25	.54	22	4.3	8.2	.0	86	6.4	.8	9.6	122	21.0	.6	18.4	3.6	6.9	35.5	5.4	.6	8.0
Gilbertsville, Ky	153	127	.90	.....	20	.39	19	4.1	7.7	.0	72	11	1.2	3.0	101	19.6	.6	18.6	4.0	7.5	34.8	10.8	1.2	2.9
Tombigbee, Epes, Ala	126	100	.82	.....	25	.63	18	1.8	10	.0	67	6.3	.6	3.0	94	25.4	.9	18.3	1.8	10.1	33.5	6.4	.6	3.0
Wabash:																								
Logansport, Ind	132	117	.85	.....	14	.23	82	35	142	.0	234	79	5.9	292	807	1.8	.0	10.7	4.6	18.5	15.1	10.3	.8	38.2
Vincennes, Ind	172	193	1.20	.....	13	.24	61	22	25	.0	230	55	6.4	36	336	3.9	.1	18.4	6.6	7.5	34.1	16.6	2.0	10.8
Wateree, Camden, S. C	259	214	.79	.....	25	.28	6.3	1.8	8.4	.0	34	4.2	.4	2.8	73	37.9	.6	9.5	2.7	12.7	25.4	6.4	.6	4.2

White:																							
Azalia, Ind..	52	48	1.18	.....	15	.14	61	23	9.5	.0	276	30	5.6	3.1	279	5.3	.1	21.5	8.1	3.3	48.0	10.6	2.0	1.1
Indianapolis, Ind	39	38	1.04	.....	14	.15	74	29	48	.0	291	58	6.1	78	450	3.1	.0	16.4	6.4	10.7	31.8	12.9	1.4	17.3
Wisconsin, Portage, Wis	7	4.6	.86	.....	13	.22	14	6.8	8.1	.0	58	17	.9	2.1	98	1.43	.3	15.4	7.5	8.9	31.5	18.8	1.0	2.3
Youghiogheny, McKeesport, Pa	141	163	1.20	18	8.5	[b]4.70	23	6.7	9.3	.0	0	123	1.1	4.5	197	4.7	[b]2.6	12.7	3.7	5.2	.0	68	.6	2.5

Approximate.

[b] $Fe_2O_3+Al_2O_3$.

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DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

WATER-SUPPLY PAPER 237

THE QUALITY OF THE SURFACE WATERS OF CALIFORNIA

BY

WALTON VAN WINKLE
AND
FREDERICK M. EATON

IN COOPERATION WITH THE CALIFORNIA DEPARTMENT OF ENGINEERING

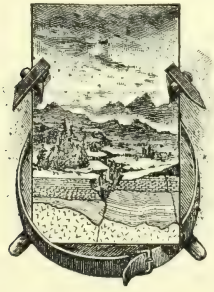

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PLATE I. Map of California showing drainage areas and location of sampling stations ..... In pocket.

THE QUALITY OF THE SURFACE WATERS OF CALIFORNIA.

By Walton Van Winkle and Frederick M. Eaton.

INTRODUCTION.

OUTLINE OF INVESTIGATION.

On the 1st of July, 1905, the Director of the United States Geological Survey made a contract with the state engineer of California for the purpose of carrying on a study of the "natural waters of the State of California, their seasonal variation in composition and in physical characteristics, and the damage which they have sustained by reason of pollution." The agreement provided that the work should be carried on by a member of the United States Geological Survey, and Frederick M. Eaton, hydrographic aid, was detailed for this purpose. Through the courtesy of the University of California, laboratory space was procured in the basement of the chemical building, and all determinations were made there.

In December, 1905, sampling stations were established at the following points:

Feather River at Oroville; gaging station at bridge.
Yuba River near Smartsville; gaging station at Narrows.
Sacramento River above Sacramento; 3 miles above railroad bridge.
American River at Fairoaks bridge; gaging station at bridge.
Mokelumne River at Clements; gaging station near bridge.
Stanislaus River at Knights Ferry; above power company's dam.
Tuolumne River at Lagrange; gaging station near bridge.
Merced River at Merced Falls; gaging station above Merced Falls.
Kern River at Oil Center; gaging station known as "First point of measurement."
San Joaquin River near Lathrop; Southern Pacific drawbridge.
Alameda Creek near Niles; above stone dam.
San Lorenzo Creek at Big Trees; at bridge.
Arroyo Seco near Soledad; gaging station at Pettit's ranch.
San Benito River near Hollister; above dam.
Santa Maria River above Santa Maria; gaging station on Dutard ranch.
Santa Ynez River near Santa Barbara; gaging station at Gibraltar dam site.
Malibu Creek near Calabasas; gaging station on Chapman ranch.
Santa Ana River above Mentone; gaging station near power house.
San Luis Rey River near Pala; gaging station near mills.

At each of these nineteen places some person was engaged and instructed to take regular daily samples from the stream at the point selected and forward them to the laboratory at Berkeley. The work was begun on January 1, 1906, with the intention of continuing it, as far as possible, without interruption until December 31, 1906; but the earthquake of April not only interrupted the collection and transportation of some samples, but destroyed others already on hand in the laboratory, and therefore certain gaps appear in the records for the year. Most of the stations were inspected by Mr. Eaton on the first part of April and last part of October, and some of the more accessible stations were also visited from time to time during the investigation.

On July 1, 1907, a new agreement was entered into by the State Department of Engineering and the United States Geological Survey, under which the work done in 1905–6 could be continued and the scope of the investigation broadened. The essential details of the new agreement were identical with those of the contract for 1905, and the work was carried out along the same general lines. Walton Van Winkle, assistant analyst in the water-resources branch of the Survey, was detailed to carry on the laboratory and field work and to compile, in collaboration with Mr. Eaton, the present report.

Sampling stations were established on the following rivers:

Russian River above Ukiah; 2 miles above town.
Cache Creek at Yolo; gaging station at bridge.
Sacramento River above Sacramento; 3 miles above railroad bridge.
San Joaquin River near Lathrop; Southern Pacific drawbridge.
Estrella River near San Miguel; one-half mile above ford.
Salinas River at Paso Robles; at wagon bridge.
San Antonio River above Bradley; at Branch's ranch house.
Nacimiento River near San Miguel; one-eighth mile above Nacimiento ranch house.
Santa Ynez River near Santa Barbara; gaging station at Gibraltar dam site.
Ventura River above Ventura; at Ventura County Power Company's diversion dam.
San Gabriel River above Azusa; gaging station near power house.
San Gabriel River near Rivera; at upper end of old canal.
Santa Ana River above Mentone; gaging station near power house.
Santa Ana River near Corona; at Auburndale bridge.
Santa Ysabel River near Escondido; gaging station near Pott's ranch.
Cottonwood Creek near San Diego; gaging station at Barrett dam.
Owens River near Tinemaha; gaging station at Charlies Butte.
Owens River near Round Valley; gaging station.

Arrangements for sampling and forwarding were the same as those during 1905–6. The collection of samples was begun in December, 1907, and the work was continued without interruption until December 31, 1908. All accessible stations were inspected from time to time. In order to obtain some knowledge of the surface waters of those sections of the State which could not be exhaustively studied,

single samples were collected by Mr. Van Winkle from the following streams:

Mad River at Blue Lake; at ford.
Eel River at Fortuna; at ferry.
Noyo River near Fort Bragg; below Alpine station.
Pescadero Creek near Hollister; at Grass Valley.
San Lorenzo Creek near Kings City; at proposed dam site.
Gaviota Creek near San Ardo; 2 miles above town.
Indian Valley Creek near San Miguel; at Douglas's ranch house.
San Juan Creek near Shandon; at ford.
Cholame Creek near Shandon; 150 feet above mouth.
Huer Huero Creek near Paso Robles; at ford on Cholame road.
Carmel River near Carmel by the Sea; 4 miles above mouth.
Rio Hondo near Rivera; at Rivera bridge.
Mohave River near Victorville; at "Narrows."
Salton Sea[a] near Mecca.

The analytical work connected with the investigation prior to March, 1906, was conducted by F. M. Eaton; for the remainder of that year the analyses were made by P. L. McCreary, field assistant. During 1908 the analyses were made by Walton Van Winkle, who was assisted during the greater part of the year by W. J. McGee, field assistant, and during the later part of the period by William Reinhart and W. C. Packard, field assistants.

A minute study of municipal water supplies was not attempted, the principal object of the work being to determine the value of the raw and undeveloped resources and the possible uses to which the water could best be put. For this purpose a broad field was covered and the results show the character of the principal drainage waters of the various areas.

In order that the report might contain statistical information regarding municipal water supply, inquiries were sent to the clerks and health officers of the 171 incorporated cities and towns of the State. Replies were received from 155, and the information is here given. The following table by George D. Leslie, statistician of the state board of health, is inserted to show the prevalence of water-borne diseases in a number of incorporated towns and cities:

Deaths from certain causes, with proportion per 1,000 total deaths, for California, 1906 and 1907.

Cause of death.	Deaths.		Proportion per 1,000 total deaths.	
	1906.	1907.	1906.	1907.
Typhoid fever	657	558	22.4	17.9
Malarial fever[b]	111	70	3.8	2.2
Diarrhea and enteritis, under 2 years	930	899	31.7	28.9
Diarrhea and enteritis, 2 years and over	338	288	14.4	9.3

[a] One sample submitted by G. K. Gilbert, United States Geological Survey; one analysis submitted by Doctor Bailey, University of Texas, Austin, Tex.

[b] Probably typhoid in part.

ACKNOWLEDGMENTS.

The University of California courteously placed laboratory space and facilities at the disposal of the Geological Survey for this work, and through its faculty aided the studies in many ways. The San Francisco office of the Forest Service, United States Department of Agriculture, furnished valuable information regarding the forests of the State. So much assistance was accorded the work by city authorities, water companies, engineers, and private individuals that it is impracticable to refer to all by name. Many of the daily samples were furnished free of charge by persons or companies interested in the work. The authors have drawn freely on the geologic reports of the University of California and of the United States Geological Survey for information relative to the geology of the State.

METHODS OF EXAMINATION.

The methods of examination employed were, with few exceptions, those outlined in Water-Supply Paper 236.[a] Departures from the procedures were made in the analyses of all rivers studied in 1906, in the determinations of suspended matter, dissolved matter, and magnesium; and in the analyses of those studied in 1908, in magnesium, alkalies, and chlorine.

In 1906 suspended matter was determined as follows: One hundred cubic centimeters of the well-shaken samples were evaporated to dryness on the water bath in a tared silver dish, dried at 100° C. for one hour, cooled, and weighed. The difference between this weight and the weight of dissolved matter, both in parts per million, represents suspended matter. Dissolved matter was determined as in the regular procedure,[b] except that the residue was dried at 100° C. for one hour. Magnesium was determined gravimetrically as the pyrophosphate, according to the method of Fresenius.[c] Potassium and sodium were determined by the indirect method from the weight of their combined chlorides and the amount of chlorine found by titrating the aqueous solution with silver nitrate.

In 1908 magnesium was determined gravimetrically as in 1906, suspended and dissolved matter being determined according to the procedure outlined in Water-Supply Paper 236.[d] Sodium and potassium were determined in a separate 250 cubic centimeter sample, as follows: The sample in a Jena beaker was made slightly acid with hydrochloric acid, evaporated to dryness on the water bath, and heated on the hot plate until no acid odor could be detected. The residue was then digested with 10 cubic centimeters of hot distilled

[a] Dole, R. B., The quality of surface waters in the United States, part 1: Water-Supply Paper U. S. Geol. Survey No. 236, 1909, pp. 9–26.

[b] Dole, R. B., op. cit., p. 13.

[c] Fresenius, C. R., Quantitative chemical analysis (transl. of 6th German ed.), vol. 1, 1906, p. 275.

[d] Dole, R. B., op. cit., pp. 12, 13.

water, barium hydrate was added in slight excess, and the solution was filtered, the precipitate being washed with hot distilled water. The filtrate from this operation was heated, and calcium and barium were removed by precipitation with ammonium carbonate and filtration. The resulting filtrate was evaporated to dryness in a porcelain dish, and heated to remove ammonium salts. The residue was then digested with 4 or 5 cubic centimeters of hot water, and treated again with ammonium carbonate to insure complete removal of calcium and barium. The solution was filtered into a small platinum dish, a small amount of hydrochloric acid added, the solution evaporated to dryness and cautiously heated nearly to fusion, cooled, and weighed. The residue in the dish was then treated with hot water, filtered through ashless filter paper, the paper being washed with hot water, ignited, and weighed in the dish. The difference between the weights was calculated to "sodium and potassium."[a]

Chlorine was ordinarily present in relatively large amounts, and the amount of this radicle was determined by direct titration of 50 cubic centimeters of water. When the amount of chlorine exceeded 40 parts per million, smaller quantities of water were used for titration, or chlorine was estimated by the gravimetric method.

EXPRESSION OF ANALYTICAL RESULTS.

The results of the analyses in this paper are stated in parts per million, the ionic form of statement being used.[b]

NATURAL FEATURES.

GEOGRAPHY.

The State of California extends from latitude 32° 40′ north to 42° north. Its average length is nearly 800 miles, its average width is about 200 miles, and its area is 155,980 square miles. The width gradually increases from a little more than 150 miles at the northern end to nearly 300 miles across the south-central part of the State, narrowing to about 150 miles at the southern end.

Two principal mountain ranges more than 100 miles apart run from northwest to southeast through the whole length of the State, a broad valley lying between. The western range, known as the Coast Range, is made up of numerous small ranges. Named in order from San Francisco Bay southward these are the Mount Diablo, Santa Cruz, Santa Lucia, San Rafael, and Santa Ynez. In southern California the Coast Range spreads out across the State in a confused mass, the Sierra Madre, San Bernardino, San Jacinto, and other chains, of which the Santa Ana and Ysidro Mountains are of the greatest importance, extending toward the south. North of San

[a] Dole, R. B., op. cit., p. 20.

[b] Dole, R. B., op. cit., p. 39.

Francisco Bay the Coast Range is made up of the St. Helena, Trinity, and Siskiyou mountains, with smaller ranges between these and the coast. The great eastern range, the Sierra Nevada, forms the eastern boundary of the State for a great part of the distance. The Klamath Mountains of volcanic origin cross the north end of the State, forming a sort of barrier between California and Oregon; and the Tehachapi, lying between the Coast Range and the Sierra in the south-central part of the State, forms the line of division between northern and southern California.

The Great Valley, lying between the Coast Range and the Sierra Nevada, is about 400 miles long and from 40 to 50 miles wide. Other large valleys, some of which are fertile and others waterless and barren, lie between the smaller ranges of the coast. South of the Sierra Madre and between the coast and the San Jacinto Mountains lies the far-famed "orange belt" of California, while beyond these mountains are the Colorado Desert and the Salton Sea.

For the greater part of its length the Coast Range follows the shore line so closely that few large rivers flow directly into the ocean, and only one of these—Salinas River—is navigable. There are therefore very few natural inlets or harbors.

CLIMATE.

A great variety of climate, ranging from fairly humid in the northwestern redwood belt, through semiarid in the Great Valley, to desert in the eastern and southeastern parts of the State, renders it difficult to discuss this subject briefly. The mean annual rainfall varies from 1 inch to 75 inches in different localities, the extremes ranging from 0 to over 100 inches. Temperatures show equally wide variation. In the desert monthly mean temperatures not much below 100° are common, with an extreme of 130°. In the Sierras in the vicinity of Lake Tahoe a temperature of −30° has been recorded, and on other high peaks temperatures ranging from −17° to −30° are common. Snowfall is in general confined to the central and northern parts of the State and to the mountains of the south.

Prof. E. W. Hilgard, of the University of California, summarizes the climates of the various sections of the State as follows:

(1) Bay and coast region characteristics: Small range of temperature, the extremes being only 53° apart. Means of summer and winter are only 6° apart. There is no intense heat, and frosts are very rare. Fogs from the sea are quite common on summer afternoons. Rainfall averages 27.3 inches, about 25 inches of which falls between December and May.

(2) Great Valley characteristics: Average winter temperatures lower than those of the coast, though minimum is about the same. Frosts are rare. Summer heat is very intense, often above 100°. The nights are warm, but dry, and are therefore less oppressive. Extreme range of temperature 76°, mean range 23.6°. Rainfall averages about 21.5 inches, of which 19.8 inches fall between December and May.

(3) Sierra slope characteristics: Cool summers with frequent thunderstorms. The winters are often severe, with much rain and snow. Mean summer temperatures, 57.5°, with a mean range of 14° between that and the winter temperature of 43.5°. Rainfall averages 57.24 inches, fairly well distributed throughout the season.

Besides these general types there are many local varieties. The predominant features can be inferred from an examination of the accompanying table, which presents summarized data for the principal stations of the Weather Bureau.

Temperature and precipitation at principal stations of the Weather Bureau in the State of California.[a]

Location.	Temperature (degrees Fahrenheit).		Precipitation (inches).	
	Mean.	Extremes.	Mean.	Extremes.
Eureka	51.5	84–20	46.04	59.62–30.91
Red Bluff	62.4	114–18	25.40	49.01–12.91
Sacramento	60.0	110–19	19.41	34.92– 8.44
San Francisco	56.1	100–29	22.75	49.27– 7.40
San Jose	58.1	104–18	14.88	25.55– 5.51
Fresno	63.0	114–20	10.13	19.45– 4.94
Independence	58.7	105–11	2.78	4.22– 2.75
San Luis Obispo	58.9	106–24	17.32	26.39– 6.93
San Diego	61.4	101–32	9.52	27.59– 3.02

[a] U. S. Dept. Agr., Weather Bureau, Bulletin L.

HYDROGRAPHY.

DRAINAGE AREAS.

California may be divided into five great hydrographic provinces:

1. The north Pacific Ocean drainage, comprising that portion of the State lying between the Oregon line on the north and the Golden Gate on the south, the Pacific Ocean on the west and the Coast Range on the east. It is a heavily wooded, broken country, contains several large rivers, and occupies 13 per cent of the State.

2. San Francisco Bay drainage, consisting of that portion of the State bounded by the Sierra on the east, the Coast Ranges on the west, the Klamath Mountains on the north, and the Tehachapi on the south. This basin divides into two smaller areas, one drained by the Sacramento, whose valley, lying between the Coast Ranges and the Sierra on the east, slopes gradually southward from Klamath Mountains; the other, which contains the San Joaquin and Tulare valleys, comprising the area lying between the Coast and Mount Diablo ranges on the west and the Sierra on the east and sloping gradually northward from the Tehachapi. These two basins unite at Suisun Bay, where a break in the coastal mountains allows their confluent waters to flow through the Straits of Carquinez into San Francisco Bay.

3. The south Pacific Ocean drainage, extending from the Golden Gate on the north to the Mexican line on the south and bordered on the east by the Coast Ranges, San Bernardino Mountains, and San Jacinto Mountains. In this area are many fertile valleys, most important of which is the valley of southern California, the center of the citrus industry of the State.

4. The interior basin, including all the land east of the Sierra and comprising two lesser divisions, designated, respectively, the minor Great Basin and the Sierra subdrainage. The waters of the interior basin are entirely landlocked, either sinking into the sands of the deserts, as do the river waters of the Mohave Desert, or flowing into dead seas, as do Owens and Susan rivers.

5. Colorado River drainage, which includes a very small portion of the southeastern corner of the State in San Bernardino, Riverside, San Diego, and Imperial counties. In general this area drains into Colorado River, but a considerable part of it discharges its run-off into Salton Sea, which lies at the northern end of Imperial Valley in a depression 273½ feet below sea level.[a] This inland sea, or sink, receives whatever drainage there is from the Coachella Valley on the northwest and from the Imperial Valley on the southeast.

LAKES.

The total water surface of California, including San Francisco Bay, is 2,205 square miles,[b] in greater part large inland lakes. Chief among these lakes may be mentioned Lake Tahoe, at an elevation of 6,225 feet;[c] Honey Lake, 3,949 feet above sea level; Owens Lake, approximately 3,600 feet; Tulare Lake, averaging about 200 feet in elevation; and Salton Sea, whose surface on December 31, 1908, stood 206 feet below sea level and whose volume is slowly diminishing. Parts of Little Klamath and Goose lakes are in Oregon, and a part of Lake Tahoe is in Nevada. The parts of the surfaces of these lakes that are outside the borders of California have been omitted in calculating the total water surface.

Many of the lakes of the State, such as Tahoe, Goose, Little Klamath, and Eleanor, are fresh, draining regularly through some well-defined outlet. Others, as, for example, Tulare Lake, have an irregular drainage, discharging through a regular channel during periods of flood, but becoming at other times landlocked seas. Still others have no outlets whatever and retain their size only by means of the adjustment between the inflowing waters and percolation and sur-

[a] Clapp, W. B., The surface water supply of California, 1906: Water-Supply Paper U. S. Geol. Survey No. 213, 1907, p. 30.

[b] Gannett, Henry, The areas of the United States, the States, and the Territories: Bull. U. S. Geol. Survey No. 302, 1906, p. 5.

[c] Gannett, Henry, A dictionary of altitudes in the United States, 4th edition: Bull. U. S. Geol. Survey No. 274, 1906, p. 131.

face evaporation. In this class are Owens and Mono lakes and Salton Sea. The mineral content of the waters of these various lakes ranges from almost nothing in the snow-fed lakes of the Sierra to thousands of parts per million in some of the inland seas. No extended study of all these lakes has been made, but a few analyses are here recorded. Owens Lake, however, is treated in somewhat greater detail, for this body of water is one of the State's valuable economic assets. Less exhaustive studies are recorded of Salton Sea, which is at present attracting the attention of engineers and scientists because it affords possibilities for solving some of the important problems of evaporation and concentration.

FLOODS.

The two periods of high water in the streams of California are caused by the rainfall of the wet season and by the melting of snow. The early rains of the wet season soak into the ground and increase the stream flow to only a slight extent. Later winter rains, usually heavier and more prolonged, fall on saturated ground and produce floods. The soil covering of humus and organic detritus upon the drainage area is washed into the streams, especially where forests and vegetation are scant.

The later floods depend for their size and violence, first, on the amount of snow on the ground at the close of winter; second, on the age of this snow; and, third, on the rapidity of climatic change. That the amount of snow is an important factor is obvious; that its age also is important requires, perhaps, a word of explanation. Newly fallen snow, if moderately dry, settles upon the ground as a light, feathery covering. Resting there it slowly settles from its own weight, becoming continually denser and more compact. Each successive snowfall presses the already compacted mass still farther, and the process of settling continues until the mass attains a hard, icelike consistency similar to that of glacier ice. Snow so compacted melts more slowly than that recently fallen. The third factor—rapidity of climatic change—is important, because slow increase of temperature will cause slow melting, while a rapid increase, especially if accompanied by rain, will cause very rapid melting.

The snow-covered areas in California lie in regions of rough and broken topography and much of the underlying soil is frozen. The melting snow therefore yields a very high percentage of run-off and very little of the soil covering is carried into the streams, the small amount so carried being for the most part in a finely divided state. Hence, although many of the floods are of great magnitude they are unaccompanied by a large increase in turbidity.

Floods caused by the rainfall of the wet season occur in all parts of the State; those caused by the melting of the snow occur only on streams which drain the higher mountain regions.

The rivers of the southern coastal region are perhaps most subject to sudden floods. Most of these streams are short "arroyos," which are without flow during the dry season, but which become swollen to raging torrents during the heavier rains of the middle and late winter. It has been found by measurement that over one-half of the total annual discharge of some of these streams occurs during a period of two weeks or less.

The winter floods of the Sacramento and San Joaquin are due primarily to the very heavy rainfall in the mountain regions and to the steep slopes of the tributary streams. Many of these rains occur simultaneously on both sides of the valley and throughout its extent. The tributary streams, swollen to flood size, pour their waters into the main river valley, causing great loss of property and temporary blocking of transportation, both by land and water. These rivers are also subject to severe floods during the spring, when the snows that have accumulated on the Sierra slopes in the winter are melted. Flowing off from the already saturated ground, these snow waters form spring floods, some of which equal or surpass in magnitude those of the winter season.

Ordinarily floods on a watershed wash off the finely divided surface soil and humus and carry these rich materials downstream to be deposited in the lower valleys. Great alluvial fans and fertile valley lands have thus been formed. But the flood waters of the Sacramento Valley have washed also from the hillsides immense quantities of material left by the placer miner and deposited it along the lower reaches of the streams. In thirty years the bed of Yuba River alone has been raised at Marysville between 20 and 30 feet and at the mouth of the canyon more than 100 feet.[a] This mass of detritus is not rich alluvial matter that will benefit the country over which it is spread, but is composed of rock, gravel, and granitic sand which will not sustain vegetation. Rivers which were formerly clear and navigable are now shallow, turbid streams, with broad, shifting bottoms, and even constant dredging scarcely serves to keep them open to vessels.

INDUSTRIAL DEVELOPMENT.

Up to the time of the discovery of gold settlements in California were mostly clustered about places which had been chosen for the establishment of the missions. These places either afforded good harbors, as San Diego and San Francisco, or possessed good agricultural and grazing lands, as Santa Barbara, San Gabriel, Soledad, and

[a] Report of State Engineer of California for 1908, p. 160.

San Juan. Later those interested went farther into the interior to the fertile valleys of the Sacramento and San Joaquin, but never far from streams of good size. Thus at this period the settlements were confined almost wholly to the coast and to the navigable streams of the State. When gold was discovered a rush for the mountains immediately began, and numerous little mining communities sprang up along the smaller creeks in the hills. Gradually commercial centers formed on the coast and in the valleys—markets through which the agriculturists found an outlet for their products and from which the mining population could obtain its supplies. With the growth of the State other industries developed, such as lumbering and fishing. As the products of the country became more numerous and diversified, manufacturing of various kinds took its place with the other industries.

The mineral output of California includes gold, silver, copper, mercury, bituminous coal, granite, sandstone, cement, borax, petroleum, mineral waters, salt, and building stones.

Irrigation is carried on extensively in all parts of the State, both surface and underground waters being used. The largest irrigated districts at present are in the San Joaquin and Sacramento valleys, which derive the greater part of their waters from the Sierra streams. Smaller districts in the valleys are watered from underground supplies.

The most important field crops of the State are hay, wheat, barley, and potatoes. Sugar beets are cultivated extensively in the San Joaquin and Salinas valleys. Citrus fruits, peaches, plums, pears, and apples are the chief orchard products.

According to the census of 1900 there were over 12,000 manufacturing establishments in the State. These had a combined capital of $205,000,000 and had products valued at $303,000,000. The products include mining and agricultural machinery; lumber for building; tanning and dressing of leather; woolen goods; flouring mills; silk fiber and fabrics; wine and brandy; refined sugar, sirup, and candies; grain bags; dynamite; giant powder; and heavy chemicals for mining use.

The census of 1900 reported also 6,890 persons employed in the fisheries of California, $3,278,500 invested as capital, and product valued at $4,872,620. The products include oysters, herring, salmon, whale, and seals.

The principal trading centers of California are San Francisco and Los Angeles. Smaller trading centers located in the valleys, such as Sacramento, Stockton, Fresno, and Bakersfield, are points of shipment for the products of these regions. San Bernardino, Riverside, Redlands, and San Diego are the greatest centers for the shipment of citrus fruits; Sacramento and San Joaquin valleys for the shipment of grain and deciduous fruits and grapes; and the north Pacific coast,

in the vicinity of Mendocino and Humboldt counties, for the shipment of redwood lumber.

NORTH PACIFIC OCEAN DRAINAGE.

DESCRIPTION.

The north Pacific Ocean drainage basin comprises a total area of 20,000 square miles and includes the counties of Del Norte, Humboldt, Trinity, and Mendocino, the greater part of Siskiyou, Modoc, and Sonoma counties, and a portion of Marin County.

The principal streams of this basin are the Klamath (whose chief tributary is Trinity River), Eel, and Russian rivers. The basin contains also many other smaller but important streams. The larger streams fluctuate in flow and their channels are as a rule normal to the mountain ranges until they reach their middle courses. Here, with one notable exception, they turn to the northwest, flowing through long, deep valleys to the coast. Immediately before entering the ocean they bend sharply to the west and join the sea at right angles to the coast line. The exception noted—Russian River—flows in a general southeasterly direction through its upper and middle course, then, turning sharply toward the sea, it enters it from the northwest. Most of the shallow coastal streams flow through short, steep valleys directly from the mountains to the ocean, cutting deep gorges in the soft sedimentary rocks of the coastal terraces.

As rainfall is generally abundant throughout this region, the stream flow is large, both in winter and in summer, and the rivers swell into torrents in the rainy season and on the melting of the snows.

Little has been written on the geology of the Coast Ranges; hence it is not possible even to summarize with accuracy or completeness the rock types there present. The few general statements made are based on the work of Professor Lawson,[a] or on personal observation. The oldest rocks of the area are probably granitic igneous rocks and pre-Cretaceous sediments. Overlying these are various later gravels, clays, sandstones, shales, and conglomerates, for the most part soft and easily weathered, and intruded here and there by basic eruptives. Many of these later sedimentaries have great thickness.

The soil is thin or lacking in the higher altitudes, but the middle and coastal sections of the area are characterized by a deep, rich soil which bears a heavy stand of redwood. The great fertility of this soil and the generally sufficient rainfall render agriculture very

[a] Lawson, A. C., Geomorphology of the coast of northern California: Bull. Geol. Dept. Univ. California, vol. 1, No. 8.

profitable, and where transportation facilities exist, as in the valley of Russian River, extensive farming industries are maintained.

The forests of the north Pacific coast area are among the most extensive in the State. According to figures of the United States Forest Service [a] there are within the Siskiyou, Klamath, and Trinity national forests, lying chiefly in this drainage basin, 560,670 acres, containing 5,211,360,000 feet b. m. of timber. The national lands of these forests comprise 3,820,195 acres, upon which is standing 31,505,337,000 feet b. m. of timber. According to an estimate made by Merrill and Hodge for the Forest Service, the coast redwood region, all of which is within this drainage area, contains 76,000,000,000 feet b. m. of redwood timber. There are also many square miles of privately owned timber land in Humboldt, Mendocino, Sonoma, and Marin counties, upon which a varied growth of evergreens is found. In Mendocino and Humboldt counties lumbering is a principal industry, and the coast cities of Eureka, Arcata, Fort Bragg, and Mendocino owe their existence chiefly to the lumber trade. The private lands are fast being deforested by large lumber camps, whose operations cause ever-increasing danger from forest fires, floods, and summer droughts.

The climate of the area is cool, the mean annual temperature being 51.2° at Eureka, 56.1° at Healdsburg, 57.6° at Ukiah, and 52.2° at Point Reyes. It is slightly cooler on the coast than in the interior. In summer the coastal region is visited by heavy fogs, which sometimes persist for weeks. During these months the rainfall is slight, but in the winter the precipitation ranges from about 30 inches in Russian River Valley to more than 120 inches in the northernmost section. The rainfall in the coastal region probably ranges from about 25 inches in the southern part to about 60 inches in the northern.

The population of the area, except along the coast and in the valley of Russian River, is small. Trinity County, in the mountainous inland district, has a population of less than 5,000; Del Norte County, an isolated, inaccessible region, has only half that number. Most of the inhabitants are concentrated in the coastal cities of Humboldt Bay and in the middle and lower valley of Russian River. The total population of the entire drainage area is about 95,000.[b]

The principal industries of the northern portion of the drainage basin are lumbering and dairying. Wherever the lumber has been cleared dairying is the chief occupation. The abundant rainfall, rich soil, rolling hills, and pure water well adapt this section to the dairy industry, and it yields some of the finest dairy products of the State.

[a] Data submitted by L. D. Woodbury, Forest Service, U. S. Dept. Agr., San Francisco, Cal.
[b] California Blue Book for 1908.

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The southern portion of the drainage area, represented by the valley of Russian River, is given over chiefly to vineyard and hop industries.

WESTERN SUBDRAINAGE.

MAD RIVER.

DESCRIPTION.

Mad River rises near the Yallo Bally Mountains, in the Trinity Range, and flows in a general northwesterly direction to the Pacific Ocean. Its basin is separated by the South Fork Mountains from the valley of Trinity River on the northeast and by steep broken ridges from the basin of Eel River on the southwest. Its valley is long and narrow, and it receives no tributaries of importance. The broken hills are of sedimentary rocks—clays, sandstones, and conglomerates forming the greater part of the strata. Forestation is heavy, lumbering is the principal occupation near the coast, and the cleared lands are used for dairying.

The river has a steep grade and in times of flood it is very dangerous. Its violence at these times suggested its name. As the basin receives an abundant winter rainfall the run-off is large, but unfortunately it has not been measured.

At Blue Lake Mad River emerges from its narrow valley and flows for a short distance in a sinuous course over a sandy plain, finally entering another narrow valley farther down.

CHARACTER OF WATER.

A sample of water was taken from Mad River directly opposite the lumber town of Blue Lake on June 10, 1908. At this time the river was at medium low stage, the velocity was high, and the water was free from suspended matter. At the point where the sample was taken the river bottom was of gravel, with short reaches of coarse sand.

The following analyses show the character of this sample and of a sample taken from Mad River a few miles below Blue Lake later in the year, through the kindness of Mr. J. B. Lentell, of Eureka. As but little drainage water enters the river between the points of sampling, the analyses are fairly comparable. The later sample was taken in the dry season, as the analysis clearly shows.

Analyses of water from Mad River near Blue Lake, California.

[Analyst, Walton Van Winkle. Quantities in parts per million.]

	1.	2.		1.	2.
Silica (SiO_2)	9.2	8.0	Bicarbonate radicle (HCO_3)	77	127
Iron (Fe)	.03	.16	Sulphate radicle (SO_4)	13	21
Calcium (Ca)	21	34	Chlorine (Cl)	3.9	6.3
Magnesium (Mg)	4.3	5.7	Nitrate radicle (NO_3)	.28	.78
Sodium and potassium (Na+K)	6.3	10	Total solids	92	153
Carbonate radicle (CO_3)	0.0	0.0	Turbidity	Trace.	Trace.

1. Sample collected by Walton Van Winkle, June 10, 1908, at Blue Lake, California. Water at medium low stage.
2. Sample collected by J. B. Lentell, on or about October 1, 1908, near mouth of Bug Creek. Discharge estimated at 600–700 inches.

These analyses indicate that although the river, even at low stage, contains little dissolved mineral matter, yet the variation in mineral content between high and low stages is considerable. In June, 1908, at time of moderately low stage, the total dissolved solids were 92 parts per million. The flood waters of the winter undoubtedly contain much less dissolved matter than that shown by the analysis of sample 1, taken in June.

The chlorine content is low—about what might be expected in a coastal stream. Chlorine is an ever-present constituent of atmospheric water, the quantity being greatest near the sea and diminishing rapidly inland. This is strikingly shown by the "isochlors"—lines of equal normal chlorine—which have been platted for the unpolluted waters of various localities and which follow rather closely the contour of the coast line. The small chlorine content of the samples analyzed does not show the presence of the surface saline deposits found so abundantly in some parts of the State. Indeed, even had such deposits been present at some former time, the heavy rainfall of the region would long since have washed them out into the streams and thence to the ocean, as such saline beds can persist only in regions of generally deficient rainfall.

The principal basic material present is calcium; the chief acid constituents are carbonates and sulphates. The greater portion of the nitrates found is probably due to vegetal material from upstream lumbering and is not the result of animal decomposition.

Engineers familiar with this river state that the water has at times a decided reddish color, due to the dissolved organic matter from the cut lumber. At such times, it is said, the water has an unpleasant laxative effect and is not well adapted for drinking. Aside from this it would, if properly protected from bacterial pollution, make an acceptable town supply. The water is of first grade for steaming and would give little or no trouble in boilers.

Another evil resulting from the lumbering industry is the clogging of the streams by sawdust, which not only increases the organic material in the water, but drives away trout and other fish.

At present the principal timber cut along Mad River is the redwood. Eventually the fir and pine forests bordering the redwood belt will be attacked, and it is possible that paper mills will be introduced. The waters of Mad River are well adapted to paper-mill use, as the small amounts of objectionable matter present could be removed by slight treatment.

EEL RIVER.

DESCRIPTION.

Eel River rises on the eastern border of Mendocino County and flows in a northwesterly direction into Humboldt Bay. Its basin is separated from that of Mad River on the northeast by a broken range of mountains, and from the valleys of Bear Creek, Mattole River, and the ocean drainage by the rough summits of the Bear River, Rainbow, and Elk ridges. It receives numerous tributaries, of which the chief and only large one, aside from its three main forks, is Van Duzen Fork. This stream, flowing from the east, joins the main river above Alton. The total area of the basin is approximately 488 square miles.[a]

The valley of Eel River is long and narrow and is broken near the source into a fan-shaped series of smaller valleys. The surface of the basin is rough and irregular, deep canyons and valleys marking the courses of the streams and high plateaus forming the tops of the ridges. The valleys have the general southeast-northwest trend common to all the valleys of this portion of the State.

The soil is rich and deep near the coast and thins out toward the summits of the coast ranges. The geologic formations include clays, sandstones, schists, and shales, with intrusions of basic igneous rocks, of which the ferromagnesian silicates form a large portion. Forests are found in all parts of the valley, the lower course of the river lying across the great coastal redwood region. Rainfall is plentiful.

Along the upper reaches of the stream there are few habitations, but toward the mouth, from Pepperwood to Humboldt Bay, there is a constantly increasing population, chiefly in lumber camps and dairy farms.

The river bottom is rocky near its source, gradually becoming gravelly and finally, near the coast, sandy. Some distance above Fortuna the river leaves its narrow canyon and flows out through its broad, flat coastal plain.

CHARACTER OF THE WATER.

A sample of the water of Eel River was taken at the ferry at Fortuna on June 11, 1908, the river being at that time at moderately low stage. At this point the bed of the stream is sandy, the river flowing

[a] Hall, W. H., Physical data and statistics of California, p. 386.

in a winding course and with swift current. Results of the analysis of the sample are here presented:

Analysis of water from Eel River at Fortuna.

[Analyst, Walton Van Winkle. Quantities in parts per million.]

Silica (SiO_2)	9.4	Bicarbonate radicle (HCO_3)	96
Iron (Fe)	.18	Sulphate radicle (SO_4)	21
Calcium (Ca)	23	Chlorine (Cl)	4.9
Magnesium (Mg)	7.0	Nitrate radicle (NO_3)	.2
Sodium and potassium (Na+K)	8.5	Total solids	112
Carbonate radicle (CO_3)	2.4	Turbidity	Trace.

Collected June 11, 1908, by Walton Van Winkle.

This analysis indicates that the water resembles that of Mad River, except that it shows some normal carbonate alkalinity and also a higher magnesium content in proportion to its total dissolved minerals.

It is said that the water of this river also causes unpleasant diuretic effects, due to organic matter added to the stream by lumbering operations; but aside from this, if proper precautions were taken to remove bacteria, the river would be a suitable source of supply for town use. It is well adapted for use without treatment for dairying and similar industries. At high stages it would undoubtedly be low in dissolved minerals, and the small amount of suspended matter could readily be removed. The water may be used without treatment for steam making.

NOYO RIVER.

DESCRIPTION.

Noyo River is a small stream rising in the Coast Range near Sherwood, in the central part of Mendocino County, flowing generally eastward, and emptying into the Pacific Ocean near Fort Bragg. Its total length is approximately 25 miles. Throughout its whole course it descends with steep slope through a narrow valley among heavily wooded mountains. The rocks in this valley, like those of the region farther north, are sedimentary and contain basic igneous intrusions.

CHARACTER OF THE WATER.

A sample of the water of Noyo River was taken on June 15, 1908, at Alpine station, about 8 miles from Fort Bragg. At this point the bottom of the river is gravelly, the current is swift, and the banks are high and precipitous. The water of this river was assumed to be typical for this section of the State, and hence samples were not

taken from other streams. An analysis of the water is presented in the following table:

Analysis of water from Noyo River, near Alpine station, Mendocino County.

[Analyst, Walton Van Winkle. Quantities in parts per million.]

Silica (SiO_2)	17	Bicarbonate radicle (HCO_3)	109
Iron (Fe)	.18	Sulphate radicle (SO_4)	18
Calcium (Ca)	20	Chlorine (Cl)	7.2
Magnesium (Mg)	7.2	Nitrate radicle (NO_3)	.64
Sodium and potassium (Na+K)	15	Total solids	132
Carbonate radicle (CO_3)	.0	Turbidity	Trace.

Collected June 15, 1908, by Walton Van Winkle.

The water is shown by the analysis to be moderately low in dissolved material. It is of the calcic carbonate type common to rivers in regions of abundant rainfall. The water is not so good for steaming as that of streams farther north, but its scale-forming materials could readily be removed. For manufacture of white paper the organic constituents would have to be removed, as they are present in sufficient quantity to cause annoyance.

SOUTHERN SUBDRAINAGE.

RUSSIAN RIVER.

DESCRIPTION.

Russian River rises in the north-central part of Mendocino County, near the town of Redwood, flows in a general southeasterly direction for about 60 miles, then turning to the southwest it empties into the Pacific Ocean. In its upper course it traverses a narrow valley surrounded by wooded hills. It receives no large tributaries, but numerous small creeks join it throughout its course.

The mountains in this area are somewhat lower and less broken than farther north on the coast, giving way to rolling hills toward the southern part of the basin, and the valley is broader and more mature. Basic magnesian rocks are also present in greater proportion than in areas farther north. The soil of the valley proper is an alluvial deposit of considerable richness.

Rainfall in this valley is plentiful. Precipitation from June to September is very light, but for the remaining months it is quite heavy, the region around Ukiah apparently receiving the smallest share. This abundant rainfall causes a very good flow in the streams, but measurements are lacking. As the foothills and mountains of the basin are in general covered with a good growth of timber, conditions are favorable for ground storage of rain water and distribution of stream flow, the summer flow being increased and the volume of the freshets diminished.

CHARACTER OF THE WATER.

A sampling station was established on Russian River about 2 miles above Ukiah late in 1907, and during 1908 samples of the water were collected daily by Miss Gertrude Howard. The valley of the river at this point is moderately wide and is bordered by foothills covered with a heavy growth of brush. The river winds through its valley in a bed of coarse sand and gravel and it receives near the town several small tributaries. The drainage area at this point is about 253 square miles.[a]

The results of the analyses are shown in the following table:

Mineral analyses of water from Russian River near Ukiah.

[Drainage area, 253 square miles. Quantities in parts per million unless otherwise stated.]

Date.		Turbidity.	Suspended matter.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.
From—	To—													
1907. Dec. 31	1908. Jan. 9	35	65	19	0.5	18	7.2	9.8	0.0	71	19	1.6	3.8	107
1908.														
Jan. 10	Jan. 19	15	24	18	.38	17	6.4	9.2	.0	83	18	1.8	4.1	116
Jan. 20	Jan. 29	60	39	17	.45	18	7.9	10	.0	71	13	1.4	4.0	101
Jan. 30	Feb. 8	50	53	19	.38	16	6.3	12	.0	67	15	.80	3.2	99
Feb. 9	Feb. 18	30	145	22	.32	14	8.2	15	.0	76	22	.77	3.0	107
Feb. 19	Feb. 28	5	.....	20	.20	21	11	12	.0	102	17	2.1	4.3	126
Feb. 29	Mar. 9	20	34	19	.43	16	8.0	14	.0	82	24	2.1	5.7	112
Mar. 10	Mar. 19	5	.....	19	.18	18	7.8	13	.0	107	17	1.1	5.1	131
Mar. 20	Mar. 29	Trace.	.....	20	.07	19	9.3	10	.0	109	15	2.0	4.2	128
Mar. 30	Apr. 8	5	.....	18	.08	20	11	9.6	.0	116	23	2.0	4.5	131
Apr. 9	Apr. 18	10	.....	17	.07	21	12	12	.0	115	17	3.0	4.5	131
Apr. 19	Apr. 28	Trace.	.....	16	.03	20	11	10	.0	118	14	1.1	4.5	127
Apr. 29	May 8	Trace.	.....	16	.03	21	11	12	.0	122	16	1.9	5.4	132
May 9	May 18	Trace.	.....	18	.06	21	12	12	.0	120	12	2.0	4.6	130
May 19	May 28	Trace.	.....	19	.15	24	12	15	[b] 3.6	112	16	.86	5.2	141
May 29	June 7	Trace.	.....	16	.15	22	12	14	.0	124	16	.96	4.6	131
June 8	June 17	Trace.	.....	16	.08	22	12	11	.0	125	16	1.0	5.9	137
June 18	June 27	Trace.	.....	15	.04	21	13	12	.0	128	12	2.0	5.5	131
June 28	July 7	5	.....	19	.18	24	13	20	.0	138	17	.66	7.0	145
July 8	July 17	Trace.	.....	24	.40	28	12	14	[b] 9.6	120	16	.92	6.0	155
July 18	July 27	Trace.	.....	20	.05	28	14	15	.0	140	15	.92	7.0	149
July 28	Aug. 6	5	.....	16	.04	23	15	14	.0	144	12	.70	7.4	148
Aug. 7	Aug. 16	Trace.	.....	20	.37	25	15	16	.0	151	18	1.4	7.5	160
Aug. 17	Aug. 26	Trace.	.....	27	.13	26	14	16	[b] 4.8	146	18	.....	8.0	172
Aug. 27	Sept. 5	4	.....	28	.43	26	15	15	.0	163	17	.56	8.0	173
Sept. 6	Sept. 15	5	.....	30	.20	23	14	14	.0	150	17	.10	8.0	179
Sept. 16	Sept. 25	Trace.	.....	21	.05	23	15	13	.0	149	17	.80	9.0	151
Sept. 26	Oct. 5	Trace.	.....	17	.04	26	14	14	.0	158	15	.52	8.0	150
Oct. 6	Oct. 15	10	.....	20	.04	30	17	23	.0	155	20	.40	11	192
Oct. 16	Oct. 25	Trace.	.....	16	.02	29	15	23	.0	166	16	.18	14	189
Oct. 26	Nov. 4	Trace.	.....	15	.04	29	16	26	.0	166	16	.28	18	187
Nov. 5	Nov. 14	Trace.	.....	15	.10	31	16	28	.0	167	16	.66	20	192
Nov. 15	Nov. 24	5	.....	17	.14	29	16	26	.0	169	19	.36	16	183
Nov. 25	Dec. 4	20	27	15	.28	25	14	31	.0	120	22	1.5	11	158
Dec. 5	Dec. 14	15	8.8	18	.38	26	13	15	.0	117	20	1.8	8.2	156
Dec. 15	Dec. 24	18	12	17	.40	24	13	15	.0	117	18	1.0	8.5	150
Dec. 25	Dec. 31	5	.....	14	.30	23	11	27	.0	115	19	1.1	8.5	144
Mean		9	.....	19	.19	23	12	16	0.0	125	17	1.2	7.4	145
Per cent of anhydrous residue		.....	.....	12	.1	14.6	7.6	10.1	39.4	.....	10.8	0.8	4.6	.....

[a] Planimeter measurement on U. S. Land Office map.
[b] Abnormal. Computed as HCO_3 in the average.

The water is of the calcic carbonate class. Chlorine is higher than in waters previously considered, averaging 7.4 parts per million. Sodium and sulphates each form about 10 per cent of the total dissolved material. Normal carbonates are encountered at rare intervals. The amount of dissolved material and the slight amount of silt and other material carried in suspension vary little throughout the year. The heavy winter rains increase the suspended matter but slightly, the greatest turbidity recorded during 1908 being only 60 parts per million during the period from January 20 to 29. The greatest amount of suspended matter, by weight, in 1908 was only 145 parts per million, February 9 to 18, when the large run-off and high velocity of the river permitted it to carry in suspension coarse-grained sand.

This water is suitable for use in boilers. Containing chiefly hardness of a temporary nature, it may be effectively treated with very small amounts of reagents and by preheating before introduction into the boiler. It is also well adapted for use in laundries, because its soap-consuming power while noticeable is not excessive. For both municipal and irrigation use it is excellent, requiring only sand filtration to make it safe and palatable for drinking. Its use without treatment in wine making will not impair the quality of the wines. Paper making may some day occupy an important place among the industries of the Russian River valley, and for this purpose slight treatment should render the water perfectly satisfactory.

NOTES ON MUNICIPALITIES.

Reports were received from 16 settlements in the north Pacific Ocean drainage area. Of these three reported water supplies obtained from wells, the others all using surface waters, wholly or in part. Three cities use filtration in connection with their water supply, the rest taking no means to insure purity of supply.

The following table gives statistics of water supply of these incorporated settlements:

Statistics of municipal water supplies in north Pacific Ocean drainage basin.

Settlement.	Drainage basin.	Population.	Stream.	Source of supply.	Nature of system.	Ownership.	Method of purification.	Per capita daily consumption (gallons).	Nature of sewerage system.	Ultimate disposal of sewage.
Arcata	Humboldt Bay	952	Humboldt Bay	Stream	Gravity	Union Water Co	None		Sanitary	Pacific Ocean.
Cloverdale	Russian River	[a] 1,200	Russian River	Russian River	Pumping	Municipal	Infiltration	100	do	Sewer farm.
Crescent City	Pacific Ocean	699	Pacific Ocean	Streams	do	Wm. L. Childers	None		Storm only	Pacific Ocean.
Etna	Klamath River	706	Etna Creek	Etna Creek	Gravity	Etna Development Co.	do		do	Creek, 2½ miles from town.
Eureka	Humboldt Bay	9,550	Humboldt Bay	Elk River	Pumping	Eureka Water Co	Alum coagulation mechanical filters.	50	Combined	Humboldt Bay.
Ferndale	Pacific Ocean	921	Salt River	Streams	Gravity and pumping.	Francis Light and Water Co.	None		Sanitary	Tide-water stream 1 mile from town.
Fort Bragg	do	[a] 2,000	Noyo River	do	Gravity	Private company	do		do	Pacific Ocean.
Fort Jones	Klamath River	437	Scott River	Wells	Pumping	G. A. Reichman	do		None	
Fortuna	Eel River	[a] 1,200	Eel River	do	do	Fortuna Water Co	do		do	
Healdsburg	Russian River	2,215	Russian River	do	do	Municipal	do		do	
Potter Valley	do	[a] 500	South Fork Russian River.	Stream and wells		Individual supplies			do	
Santa Rosa	do	7,980	Santa Rosa Creek.	do	Gravity	Municipal and Santa Rosa Water.	Sedimentation and filtration.	235	Sanitary (septic tank).	Sewer farm.
Ukiah	do	2,170	Russian River	do	Gravity and pumping.	Ukiah Water Improvement Co.	None	300	Combined	Do.
Willits	Eel River	791	Deep Creek	Streams	Gravity	Willits Water and Power Co.	do		None	
Yreka	Klamath River	1,384	Yreka Creek	Stream and wells	Gravity and pumping.	Municipal	do		Combined (septic tank).	Yreka Creek.

[a] Based on estimates of city or town clerks and health officers. All others estimated for 1909 from United States census, 1890 and 1900.

SAN FRANCISCO BAY DRAINAGE.

DESCRIPTION.

The San Francisco Bay drainage area comprises a large basin or valley extending lengthwise throughout the northern and middle portions of the State and rimmed in on all sides by mountains, the only outlet being the narrow break in the coastal hills at the Straits of Carquinez. The northern extremity of this area lies on the crests of the broken ranges which form the Klamath Mountains. The summits of the Sierra on the east, of the Tehachapi on the south, and of the Coast Ranges on the west complete the bordering rim. Inclosed within this oval of mountains are 64,000 square miles of land surface—about 40 per cent of the total area of the State. The northern portion of the basin makes the Sacramento Valley, the middle portion the San Joaquin Valley, and the southern portion, separated from the San Joaquin Valley by a low, alluvial divide, the Tulare Valley. These three valleys form a long, narrow plain, having an average width of 50 miles and a length of 400 miles, and include about 20,000 square miles of valley land.[a] On the west the Coast Ranges rise with great abruptness from the alluvial plain, while on the east the rise is gradual and in places almost imperceptible, forming a long, gentle slope to the summits of the Sierra, from 6,000 to 10,000 feet above the valley floor.

The area is drained by the two largest rivers in California, the Sacramento and the San Joaquin, which unite at Suisun Bay. A number of other streams, important merely as sources of water supply for the bay cities of San Francisco, Alameda, Oakland, and Berkeley, and the smaller towns, empty directly into San Francisco and San Pablo bays, the most important of these being Alameda Creek and Coyote River in the southern portion and Napa Creek on the northern shore.

The rock floor of the Sierra Nevada region consists of metamorphosed sediments and eruptives and later intrusive granitic or dioritic masses, except where scattered late effusives—rhyolites, andesites, and basalts—appear, or where weathering and stream action have caused local deposits, such as the auriferous gravels of the Tertiary period.

The soil of the San Francisco Bay drainage area can not be considered as a unit, owing to the extent of the area, the varying character of the bed rock, and the vast differences in climatic conditions and in alluviation. In the high regions of the Sierra there is little soil of any kind, but toward the valley the rich, iron-bearing, red soil

[a] Ransome, F. L., The Great Valley of California: Bull. Dept. Geology Univ. California, vol. 1, No. 14, p. 373.

of the slopes increases steadily in depth. Lower down in the foothills is a great depth of rich red soil, interspersed here and there with clay deposits and giving place locally to white ash or to black adobe soils. The valley floor is alluvium, portions of it semisubmerged, as tule swamps, and other portions choked with alkali. The soil of the Bay region is largely black adobe, merging into alluvium on the one hand and bed rock on the other.

The northern and eastern slopes of this drainage area are generally well forested, while, except in the northwestern portion, the western slopes are nearly bare. Much of the forest land is now held as national forests, but skirting these reserves are large areas of privately owned timber lands, extending from the Shasta National Forest on the north to the Stanislaus Forest on the south, and containing probably over a million acres.

In the reserved lands are 11,451,565 acres of woodland, comprising the Shasta, Lassen, Plumas, Tahoe,[a] Stanislaus, Sierra, and Sequoia national forests. It is estimated[b] that these national forests contain 53,961,213,000[c] feet b. m. green saw timber, as well as about 35,000,000 feet cordwood and over 375,250 feet dead saw timber. The private timber claims within the limits of the national forests mentioned contain about 28,542,350,000 feet b. m. merchantable timber. It is estimated that in the Yosemite, General Grant, and Sequoia national parks the total stand is 3,949,120,000 feet b. m. merchantable timber, and 6,380,896 cords of wood. Thus, with the private timber standing upon unreserved lands, the total amount of timber in the basin is very close to 90,000,000,000 feet b. m. 43 per cent of the total timber of the State. Almost all of this stands within the borders of the San Francisco Bay drainage area, small sections only over lapping into the north Pacific and Interior Basin drainage areas.

The principal industries of the Great Valley include mining, smelting, lumbering, dairying, grazing, orchard farming, graniculture, sugar manufacture, and fishing. The chief mine products are gold and copper, and there are also extensive quarries of granite, sandstone, and other rocks, and a number of mineral springs of economic importance. Dairying is growing rapidly in importance, as are also all agricultural industries except wheat production. Rice culture has recently been started in Glenn County.[d] In the alluvial plain and foothill regions agriculture, fruit growing, and dairying are the principal industries.

Fishing as an industry deserves more prominent mention than is usually given to it. Sacramento River alone yields annually nearly

[a] Excluding 57,675 acres in the State of Nevada.

[b] Communicated by T. D. Woodbury, acting chief of silviculture, District 5, U. S. D. S., Forest Service, March 12, 1909.

[c] Including dead timber of the Stanislaus National Forest, for which estimate is lacking.

[d] Eighteenth Ann. Rept. California State Board of Trade, 1908, p. 23.

$1,250,000 worth of fish, representing about one-third of the total catch for the State. This whole industry is threatened with destruction if steps are not taken to prevent the pollution of the streams by mining and industrial wastes and municipal sewage. Directly above the city of Sacramento scores of fishermen's houseboats are anchored along the banks. The fish caught by these men are sold chiefly in such places as Sacramento and the bay cities. The river at Sacramento is a muddy, uninviting-looking stream, containing, besides all manner of débris, more or less pollution from all the settlements in the drainage area. The fish will eventually disappear from the river as the pollution becomes more pronounced. Acid and other industrial wastes, although at present not of great enough extent to be important, should nevertheless be prevented from contaminating the river and its tributaries, and sawdust from mills should not be allowed to fill the beds of the smaller streams to the destruction of the brook trout.

In some sections of this drainage area extensive irrigation projects are in construction or operation, while in other sections schemes for draining the fertile tule lands are being considered. According to the state engineer, the proper control of Sacramento River, together with necessary irrigation and the drainage of the tule swamps, would add to the permanently available area of the Sacramento Valley 1,000,000 acres.[a] The Reclamation Service is constructing a dam and an impounding reservoir on Stony Creek, in Glenn County, and on the completion of this project 14,000 acres will be placed under irrigation.

In the southern sections of the area, in the Tulare and San Joaquin valleys, the principal industries are grain and fruit raising, grazing, and mining. The Sierra slopes are used for grazing, for fruit growing, and for mining. In the western portion of the valley, near Coalinga and at Bakersfield, the pumping and refining of asphaltum and petroleum are the chief industries.

SACRAMENTO RIVER SYSTEM.

DESCRIPTION.

The Sacramento Valley, which lies between the Sierra Nevada on the east, the Klamath Mountains on the north, and the Coast Range on the west, is narrow and winding at its northern extremity, in places scarcely 10 miles wide, but near Red Bluff it widens out abruptly and becomes a broad, alluvial valley floor, sloping gently southward to its junction with the San Joaquin Valley. Sacramento River, the largest stream in California, rises in the Shasta Mountains and winds tortuously along the axis of the valley, skirting the steep bases of the Coast Ranges on one side and the long, gentle slopes of the

[a] Rept. State Engineer of California for 1908, p. 65.

Sierra Nevada on the other. The river flows in a general southerly course for about 200 miles; then turning to the west it meanders sluggishly through tule swamps into Suisun Bay. Thence its waters pass through the Straits of Carquinez into San Pablo Bay and reach the Pacific by way of San Francisco Bay and the Golden Gate.

The river drains all of the territory south of Mount Shasta between the Coast Range and the Sierra Nevada. The portion of the drainage basin above Red Bluff extends from the Trinity Mountains on the west to the Warner Mountains, near the California-Nevada line, on the east. The area on the west, bordered by the Trinity Mountains, is comparatively narrow—ranging in width from 10 to 35 miles—and furnishes a very small proportion of the discharge of the river, but that on the east includes Pit River, the most important tributary. The western portion of the basin is well timbered, as is also that portion of the drainage area in the Sierra Nevada lying between Mount Shasta and Lassen Peak. Farther east, however, there is little or no forest covering, and the country is used extensively for pasturage.

Below Red Bluff the Sacramento enters a long, broad, flat valley, through which it flows on a comparatively light grade until it reaches Suisun Bay. In its course through the valley it receives many tributaries, the largest from the eastern side.

Farming is the principal industry in this region. On the tributary streams mining and lumbering are followed extensively. Many large towns on the banks of the river owe their existence to the shipping which is carried on by boat and rail. The fishing trade is also very important along the Sacramento. In the central part of the valley considerable areas are given up to the cultivation of sugar beets.

TRIBUTARIES.

The Sacramento receives numerous important tributary streams from the Sierra and smaller ones from the Coast Ranges. At many places in its middle and lower course the river is bordered by tule swamps, in which the smaller western tributaries lose themselves, few of them reaching the Sacramento through well-defined channels. The larger and stronger tributaries from the east, however, have formed definite and regular channels that run directly to the main river. Most of these tributary streams from the Sierra flow southwestward, forming deep, narrow canyons, which give to the otherwise gently sloping land a very rugged appearance. The streams rising in the Coast Ranges, however, cut much smaller canyons, most of them trending distinctly west-east.

Pit River, the largest tributary of the Sacramento, drains an area extending about 120 miles eastward from the main stream and lying between Mount Shasta on the north and Lassen Peak on the south.

The greater part of this basin is composed of lava and shows other evidences of volcanic activity, such as volcanic cones and craters. Nearly all the tributaries of Pit River rise in large springs. The most important tributary of the Pit is the McCloud, which drains the southern slope of Mount Shasta and derives its waters principally from the melting snow from the high elevations of this mountain.

The principal tributaries below Red Bluff are Feather and American rivers, draining the western slopes of the Sierra, and Stony, Cache, and Putah creeks, draining the eastern slopes of the Coast Ranges.

The following table shows the names, relations, and geographic order from north to south of the more important tributaries of the Sacramento:

Principal tributaries of Sacramento River.

From the west.	From the east.	
Clear Creek.		
Cottonwood Creek—North Fork.	Pit River—North Fork.	
Cottonwood Creek—Middle Fork.	Pit River—South Fork.	
Cottonwood Creek—South Fork.	Ash Creek.	
Red Bank Creek.	Falls River.	
Toms Creek.	Hat Creek.	
Stony Creek.	Burney Creek.	
Willow Creek.	Squaw Creek.	
Cache Creek.	McCloud Creek.	
Puta Creek.	Cow Creek.	Butte Creek.
	Mills Creek.	Deep Creek.
	Chico Creek.	Big Butte Creek.
	Feather River—North Fork.	
	Feather River—Middle Fork.	
	Feather River—South Fork.	
	Honcut Creek.	
	Yuba River—North Fork.	
	Yuba River—Middle Fork.	
	Yuba River—South Fork.	
	Bear River.	
	American River—North Fork.	
	American River—Middle Fork.	
	American River—South Fork.	
	Rubicon River.	

The streams here described are typical, and descriptions of the others are therefore not given in this report.

SACRAMENTO RIVER AT SACRAMENTO.

CHARACTER OF WATER.

Samples of water for this investigation were collected from the river at a point about 3 miles above the railroad bridge at Sacramento, where the stream is wide, shallow, and sluggish at low stages, but during flood periods is exceedingly swift and liable to overflow.[a]

[a] For data concerning gage heights and discharges of the river at the Red Bluff gaging station, see Water-Supply Papers U. S. Geol. Survey Nos. 81, 100, 134, 177, and 213.

The chemical analyses (see table following) show that the water of Sacramento River should be classed as carbonate—calcium, magnesium, and bicarbonates forming the greater part of the dissolved mineral matter. The total dissolved material is not high, and the water is fit for almost any industry that can use moderately hard water. It may readily be softened, however, by adding to it a small amount of soda ash, which will remove the excess of lime and magnesia.

Mineral analyses of water from Sacramento River above Sacramento.

[Parts per million unless otherwise stated.]

Date.		Turbidity.	Suspended matter.	Silica (SiO_2).	$Fe_2O_3+Al_2O_3$.	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Total solids.
From—	To—													
1906.	1906.													
Jan. 1	Jan. 10	.....	10	31	2.4	14	6.5	18	3.0	0.0	89	8.4	6.9	144
Jan. 11	Jan. 20	.....	210	27	2.8	11	5.1	21	2.8	.0	121	18	18	118
Jan. 21	Jan. 30	.....	174	20	.8	15	6.2	18	.8	.0	46	19	5.9	56
Feb. 4	Feb. 9	.....	.....	28	5.4	11	6.1	12	.9	.0	73	10	8.2	176
Feb. 10	Feb. 17	.....	96	24	2.4	13	5.9	9.5	2.5	.0	73	10	7.6	106
Feb. 22	Mar. 1	.....	122	16	4.2	11	6.0	8.5	1.1	.0	59	14	9.0	66
Mar. 2	Mar. 11	.....	62	18	5.8	15	9.5	11	2.3	.0	58	25	7.4	130
Mar. 12	Mar. 21	.....	22	16	6.0	12	4.8	7.1	4.2	.0	60	8.4	8.3	212
Apr. 1	Apr. 4	.....	114	10	4.0	13	8.4	12	1.8	.0	49	14	5.1	104
Apr. 12	Apr. 20	.....	54	16	6.8	14	6.2	11	2.3	.0	57	9.7	4.9	102
Apr. 21	Apr. 30	.....	58	13	4.4	12	6.0	8.7	1.9	.0	58	8.2	4.9	112
May 1	May 9	.....	56	9.2	4.8	13	6.1	6.3	1.3	.0	58	8.2	5.9	98
May 10	May 20	.....	26	15	3.6	14	5.9	7.4	1.2	.0	53	8.7	6.4	80
May 21	May 30	.....	42	10	2.8	11	5.5	6.0	0.9	.0	54	13	6.2	88
May 31	June 10	.....	24	20	4.2	13	5.2	9.6	2.1	.0	50	16	6.2	100
June 11	June 20	.....	22	15	4.0	12	10	10	1.7	.0	51	16	6.7	94
June 21	June 30	.....	32	12	4.8	13	4.9	12	.....	.0	53	7.1	6.8	80
					Fe.									
July 1	July 10	.....	18	16	.20	14	6.8	16		.0	66	13	5.8	106
July 11	July 20	.....	10	32	.50	16	5.9	10		.0	73	16	7.8	126
July 21	July 31	.....	50	19	.10	16	5.9	15		.0	81	12	7.2	130
Aug. 1	Aug. 10	.....	16	36	.08	21	9.3	21		.0	102	17	13	176
Aug. 11	Aug. 20	.....	28	23	.15	17	9.0	19		.0	102	16	14	162
Aug. 21	Aug. 31	.....	46	15	.13	17	8.1	18		.0	98	15	16	142
Sept. 1	Sept. 10	.....	56	22	.25	15	8.1	19		.0	100	15	13	136
Sept. 11	Sept. 20	.....	42	21	.30	19	9.5	16		[a]2.0	96	14	13	148
Sept. 21	Sept. 30	.....	42	24	.20	17	8.5	19		.0	97	16	12	154
Oct. 1	Oct. 10	.....	38	18	.25	19	7.8	19		.0	90	12	12	138
Oct. 11	Oct. 20	.....	18	26	.35	18	9.3	19		.0	104	14	9.1	150
Oct. 21	Oct. 31	.....	24	25	.17	14	7.7	13		.0	98	8.2	8.1	134
Nov. 1	Nov. 10	100	60	17	.75	15	6.3	18		.0	88	13	8.1	120
Nov. 11	Nov. 20	20	46	21	.25	16	7.1	14		.0	102	13	8.6	146
Nov. 21	Nov. 30	20	.....	18	.35	14	6.9	27		.0	90	16	8.6	156
Dec. 1	Dec. 10	15	54	22	.20	17	7.9	15		.0	93	8.7	8.1	118
Dec. 11	Dec. 20	100	140	18	.20	15	5.0	13		.0	55	16	7.7	118
Dec. 21	Dec. 31	100	152	6.0	.8	14	5.9	26		.0	55	14	9.2	100
Mean		.....	60	19	[b].29	15	7.0	15		.0	76	13	8.7	124
Per cent of anhydrous residue		.....	.....	16.6	.2	13.0	6.1	13.0		32.2	.....	11.3	7.6	.....

[a] Abnormal. Computed as HCO_3 in the average.

[b] Mean of Fe values after July 1.

Mineral analyses of water from Sacramento River above Sacramento—Continued.

Date.		Turbidity.	Suspended matter.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.
From—	To—													
1907. Dec. 31	1908. Jan. 9	230	360	26	1.0	13	5.1	10	0.0	54	21	1.0	4.3	104
1908. Jan. 10	Jan. 19	115	102	24	.51	16	7.0	5.2	.0	56	25	1.4	4.9	114
Jan. 20	Jan. 29	85	106	24	.40	13	2.0	11	.0	49	16	1.1	4.1	104
Jan. 30	Feb. 8	75	117	27	.51	12	3.1	15	.0	50	24	.80	4.0	105
Feb. 9	Feb. 18	100	135	36	.80	11	5.9	11	.0	51	23	1.6	4.4	105
Feb. 19	Feb. 28	85	91	28	.30	13	6.4	10	.0	68	18	.37	6.0	107
Feb. 29	Mar. 9	50	91	27	.48	15	4.8	17	.0	71	25	.34	5.1	111
Mar. 10	Mar. 19	85	178	30	.75	13	6.1	13	.0	71	13	1.0	5.1	113
Mar. 20	Mar. 29	95	175	27	.50	13	4.0	9.5	.0	61	26	.48	3.6	107
Mar. 30	Apr. 8	20	148	27	.50	13	5.7	15	.0	63	21	Tr.	4.1	102
Apr. 9	Apr. 18	110	332	21	.85	10	5.2	10	.0	59	20	.70	4.0	85
Apr. 19	Apr. 28	135	100	26	.55	11	4.4	8.8	.0	55	16	1.0	3.4	94
Apr. 29	May 8	108	92	22	.28	9.7	4.4	8.8	.0	52	17	.68	4.0	88
May 9	May 18	40	48	19	.23	10	8.1	7.1	.0	56	13	.74	2.5	86
May 19	May 28	95	61	18	.30	9.7	3.8	5.8	.0	54	9.9	.....	2.5	80
May 29	June 7	50	52	19	.38	12	4.7	8.5	.0	56	13	.48	3.4	81
June 8	June 17	50	43	22	.25	12	3.7	9.0	.0	59	11	1.0	4.2	89
June 18	June 27	45	46	26	.38	12	6.7	12	.0	71	18	.22	7.0	112
June 28	July 7	55	77	33	1.0	12	7.3	13	.0	73	13	.70	7.0	132
July 8	July 17	50	81	28	.38	15	9.4	11	.0	84	18	.92	6.5	124
July 18	July 27	60	78	24	.18	14	7.9	13	.0	87	12	1.2	6.0	118
July 28	Aug. 6	50	145	27	.31	16	10	14	.0	89	16	.....	7.5	122
Aug. 7	Aug. 16	40	55	29	.25	16	8.7	16	[a] 1.2	99	16	.40	7.2	131
Aug. 17	Aug. 26	45	97	32	.20	15	9.3	17	.0	95	16	.56	8.0	131
Aug. 27	Sept. 5	30	58	29	.60	16	9.4	16	.0	95	16	.78	8.0	134
Sept. 6	Sept. 15	30	58	34	.38	17	7.9	15	.0	96	16	.10	7.2	132
Sept. 16	Sept. 25	25	43	24	.21	15	8.0	14	.0	92	16	.30	6.5	120
Sept. 26	Oct. 5	45	68	29	.04	14	8.9	11	.0	96	13	.54	5.5	120
Oct. 6	Oct. 15	50	80	33	.13	14	8.3	14	.0	93	21	.40	6.5	126
Oct. 16	Oct. 25	85	126	31	.55	13	7.8	15	.0	82	18	.50	6.6	123
Oct. 26	Nov. 4	65	116	31	.18	12	7.9	17	.0	85	13	.32	5.9	114
Nov. 11	Nov. 14	40	75	28	.18	12	7.1	19	.0	87	12	.20	4.0	117
Nov. 15	Nov. 24	45	76	34	.40	12	8.7	16	.0	85	14	.30	5.6	128
Nov. 25	Dec. 4	45	84	28	.40	15	7.9	15	.0	77	17	.44	6.0	114
Dec. 5	Dec. 14	50	90	43	.50	14	7.3	13	.0	81	15	.70	6.2	138
Dec. 15	Dec. 24	50	63	31	.45	14	7.2	19	.0	83	13	.48	6.2	128
Dec. 25	Dec. 31	30	38	40	.60	15	9.8	23	.0	87	16	.54	7.0	140
Mean		66	102	28	.43	13	6.7	13	.0	74	17	.64	5.4	113
Per cent of anhydrous residue				23.2	0.4	10.8	5.6	10.8	30.0		14.1	0.5	4.6	

[a] Abnormal. Computed as HCO_3 in the average.

At high stages the water is exceedingly turbid and the suspended matter is fine and does not settle readily. At other seasons the water is not so turbid, but it is not very clear at any time.

The water of the river is used to some extent for irrigation and for the municipal supplies of several small towns along its course, and forms the main source of supply for the city of Sacramento. The water is pumped into the mains from the river without any treatment, the users depending solely upon faucet filters for its purification. Owing to the possibility of sewage contamination from the towns on its banks and from the boats that are constantly passing up and down the river, its water can not be recommended for domestic use unless it is thoroughly purified.

CACHE CREEK.

DESCRIPTION.

Cache Creek rises in Clear Lake, which lies in a narrow valley in the central part of Lake County directly west of the St. Helena Mountains. The lake is about 22 miles long and 7½ miles wide, extends generally northwest and southeast, and receives the drainage from approximately 500 square miles of land. Cache Creek, flowing toward the southeast, finally disappears in the swamp lands below Yolo, the total drainage area above Yolo being 1,230 square miles. Several tributaries join the creek in its short course, the largest of these being the North Fork, which rises to the northeast of Clear Lake and flows generally parallel to that body of water, joining Cache Creek at the point where that stream turns to the southeast. A short distance above Yolo Cache Creek emerges from the foothills and crosses a narrow alluvial plain extending from the foothills to Sacramento. Practically none of the water of the creek finds its way above ground to the Sacramento during the summer months, because of its extensive use for irrigation near Yolo.

CHARACTER OF WATER.

Waters of the region.—In the vicinity of Clear Lake are mercury deposits of considerable importance, and other evidences of intrusive disturbances appear in the numerous mineral springs of the vicinity. In a monograph relating to the mercury deposits of this section G. F. Becker[a] cites analyses of two of the sulphur springs, and these analyses are reproduced here to indicate the character of the soluble mineral matter of this region. An analysis of the water of Borax Lake, from the same source, is also given here.[b]

[a] Becker, G. F., Mon. U. S. Geol. Survey, vol. 13, 1888, p. 259.

[b] Idem, p. 265.

Analyses of waters of Sulphur Springs, Borax Lake, and Clear Lake.

[Parts per million.]

	Sulphur Springs.		Borax Lake.[a]	Clear Lake.[b]
	Hermann shaft.	Parrott shaft.		
Silica (SiO_2)	37	42	11	7.9
Alumina (Al_2O_3)	.....	.....	2.9	.2
Ferric oxide (Fe_2O_3)	.....	.68	3.8	.....
Manganese (Mn)	.....	.....	.86	.....
Calcium (Ca)	21	20	24	20
Magnesium (Mg)	5.5	1.6	273	13
Sodium (Na)	1,706	1,319	29,167	5.2
Potassium (K)	25	39	1,064	2.3
Ammonium (NH_4)	2.4	1.1	.....	.....
Borate radicle (B_4O_7)	1,451	1,857	3,866	.....
Carbonate radicle (CO_3)	1,140	220	17,198	66
Sulphate radicle (SO_4)	17	466	98	4.1
Chlorine (Cl)	693	667	24,812	2.2
Bromine (Br)	.....	.....	30	.....
Phosphate radicle (PO_4)	.....	.....	15	.....
Organic matter	.....	.....	3,618	34
Hydrogen sulphide (H_2S)	4.6	.74	.....	.....
Carbon dioxide (CO_2)	262	1,751	684	.....
Fixed organic matter	5.0	7.6	.....	.....
	5,370	6,393	80,868	155

[a] Analyst, Doctor Melville. [b] Analyst, Professor Price.

Borax Lake was, at the time of Becker's description, a small shallow pond. It was at one time a part of Clear Lake but was subsequently cut off from it and deprived of all outlet except, possibly, during rare periods of overflow. The analysis is cited here to show the unusual magnesium content of the lake waters as compared with the calcium content, and also to show the presence of large quantities of borax in the waters of both lake and springs. An analysis of the water of Clear Lake, made by Professor Price, in 1874, for the city of San Francisco, and cited by A. E. Chandler in his paper on the water-storage possibilities of Cache Creek[a] also given, shows the radically different character of this water and at the same time the high magnesium content peculiar to the waters of this region. Clear Lake contained at the time of the sampling considerably less dissolved mineral matter than was found at any time in the water near Yolo. However, except for large differences in percentage composition of alkalies, chlorides, and sulphates, the relations of the elements are similar. It is possible that the sample from Clear Lake was taken after a period of heavy rainfall, when the chlorine and alkali content would be low, and it is probable that the average content is greater than that recorded.

In Borax Lake, where the water exists in a closed basin, the magnesium-calcium ratio attains the surprising value of 11½ to 1, while in Clear Lake, immediately adjacent, the ratio is 1 to 1½.

Waters of Cache Creek at Yolo.—At the town of Yolo the course of the creek is practically straight for a quarter of a mile, and its

[a] Water-Supply Paper U. S. Geol. Survey No. 45, p. 33.

steep banks are crowned by protecting levees and by a growth of small trees. The river bottom is gravelly, with loamy stretches, and, except at low stage, the current is swift. As the bed is sandy and gravelly for a long distance upstream, the water shows high turbidity in flood season. During 1908 daily samples were collected by Mrs. Cornelia Bigelow at the United States Geological Survey's gaging station until August 7; for the remainder of the year the river was dry.

In the early part of the year the rainfall was heavy, and for the period between January 30 and February 8 the run-off reached an average of 4,711 acre-feet a day. This period was also the period of maximum suspended matter, but not of minimum dissolved matter, which occurred in the following ten days and resulted from a greatly decreased sodium and chlorine content. The flood waters receded after the middle of February, and there was a short period of lower discharge, followed by another flood period between February 29 and March 10. The turbidity at this time was much less—the soil had recently been washed clean of easily transported detritus and time for new accumulations was small—attaining an average of only 150 parts per million, as compared with 500 parts in the previous flood. The minimum value for dissolved matter was again found ten days later, this time not because of any change in the sodium chloride content, but because of decrease in amount of alkaline earths and carbonates. Sulphates and chlorides also show a slight diminution in the later analysis. From this time on the records show a steady decrease in stream flow and suspended matter and a fairly constant increase in dissolved mineral matter until the surface flow ceased entirely, when a maximum of nearly 300 parts per million was reached.

The results of the chemical analyses are presented in the accompanying table. The water is of the calcic and magnesic carbonate type. Normal carbonates were noted at various times, especially during the early part of July, when the tests showed about 12 parts per million. The water may be fitted for municipal use by sedimentary and bacterial purification. In its raw state it is not suited for use in laundries, as its high magnesium content and its relative hardness would cause fairly large consumption of soap. For economical steam production the addition of small amounts of softening reagents is desirable.

Mineral analyses of water from Cache Creek at Yolo.

[Drainage area, 1,230 square miles. Quantities in parts per million unless otherwise stated.]

Date.		Turbidity.	Suspended matter.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.	Mean discharge.		Run-off per square mile (cubic feet per second).
From—	To—														Acre feet per day.	Cubic feet per second.	
1907.	1908.																
Dec. 31	Jan. 9	145	162	19	0.19	35	23	44	2.4	173	35	1.5	47	290	1,448.0	730.2	0.5936
1908.																	
Jan. 10	Jan. 19	85	64	26	.20	31	23	56	.0	198	34	1.08	47	298	1,102.8	556	.4520
Jan. 20	Jan. 29	155	239	22	.42	33	23	33	.0	170	29	1.6	32	241	2,155.2	1,086.8	.8826
Jan. 30	Feb. 8	500	560	20	.25	24	18	30	.0	151	24	.66	26	210	4,711.3	2,375.3	1.9311
Feb. 9	Feb. 16	230	366	16	.41	28	19	25	.0	160	25	.40	20	198	4,385.5	2,211	1.7975
Feb. 19	Feb. 28	20	33	15	.18	31	22	28	.0	185	30	.20	24	233	2,164.1	1,091.3	.8872
Feb. 29	Mar. 9	150	134	17	.31	29	21	25	.0	181	31	1.3	24	224	3,453.7	1,741.7	1.4161
Mar. 10	Mar. 19	18	....	14	.30	24	19	25	4.8	174	28	1.2	21	212	2,381.7	1,201	.9764
Mar. 20	Mar. 29	10	....	11	.05	26	22	27	7.2	172	23	.80	22	216	1,895.7	955.8	.7771
Mar. 30	Apr. 8	10	....	14	.15	28	23	25	.0	180	35	1.5	23	225	1,575.8	794.7	.6461
Apr. 9	Apr. 18	15	....	12	.28	28	21	30	.0	188	38	1.1	24	229	1,351.9	681.6	.5542
Apr. 19	Apr. 28	20	20	15	.13	28	20	27	.0	193	25	2.0	26	235	1,155.0	582.3	.4734
Apr. 29	May 8	Tr.	....	9.4	.11	28	22	29	.0	195	26	1.0	27	238	859.0	433.1	.3521
May 9	May 18	5	....	11	.05	30	25	29	2.2	191	20	1.6	29	242	628.7	317	.2577
May 20	May 28	10	....	16	.35	31	25	35	.0	200	31	2.0	29	261	499.2	251.7	.2046
May 29	June 7	10	....	17	.09	31	24	35	9.6	194	27	....	34	261	284.2	143.3	.1165
June 8	June 17	10	....	13	.19	33	26	37	.0	220	27	1.8	36	277	147.5	74.4	.0605
June 18	June 27	Tr.	....	12	.13	32	27	35	Trace.	224	22	1.5	35	272	69.6	35.1	.0285
June 28	July 7	10	....	15	.13	33	27	41	4.7	220	28	.65	37	283	19.0	9.6	.00780
July 8	July 17	Tr.	....	24	.18	35	27	36	12.	209	27	2.0	36	287	8.13	4.1	.00333
July 18	July 27	10	....	18	.08	30	26	41	3.6	229	26	2.0	37	291	5.36	2.7	.00219
July 28	Aug. 2[a]	5	....	18	.06	37	29	41	Trace.	243	28	1.8	37	282	1.98	1.0	.00081
Mean		64	....	16	.19	30	23	33	2.1	193	28	1.3	31	250	1,377	694	.57
Per cent of anhydrous residue		....	....	6.2	0.1	11.6	8.9	12.7	37.6	....	10.7	0.5	11.7	....	.....	.....	.....

[a] Creek dry during the rest of the year.

FEATHER RIVER.

DESCRIPTION.

Feather River drains a portion of the western slope of the Sierra Nevada, extending eastward almost to the Nevada line, a distance of nearly 75 miles, and north and south a distance of 30 to 40 miles. The general course of the stream is west to southwest to the point at which it empties into Sacramento River near Verona.

The Feather receives numerous tributaries, the principal ones being the North, Middle, and South forks. The greater part of the basin is rough and mountainous. The bed rock in the southern and eastern parts of the basin is granite, on which rests the comparatively deep soil. Lava and other volcanic materials cover considerable areas in the middle and northern portions of the basin. The ground storage provided by the many meadows and valleys tends to maintain a steady stream flow during the summer months.

The entire basin, except the meadow lands, is well covered with a growth of brush and timber, much of which is large enough to make lumbering a profitable industry. The meadow lands are used for

stock raising and grazing. Numerous large springs are found, especially in the lava districts, which supply a more or less constant flow throughout the year. Little artificial storage has been developed in the drainage area, and the water used for irrigation in the valleys is taken from the natural flow of the stream.

The principal industries of the region are mining, stock raising, lumbering, and power development in the upper basin, while in the lower valleys agriculture and placer mining or dredging compete for mastery of the ground.

CHARACTER OF WATER AT OROVILLE.

Samples for this investigation were collected by the gage reader at the gaging station near Oroville.[a] The river at this point flows in a rocky channel filled with coarse gravel. The current is sluggish at low stages and very swift at flood seasons.

During the winter and early spring the river is swollen from heavy rains and at this time carries a large quantity of suspended matter. Later in the season another period of high water is caused by the melting snow on the mountains, but at this time a much smaller proportion of suspended matter is carried and the water is of better quality.

Results of the analytical study are presented in the following table. Calcium, magnesium, and bicarbonates constitute the greater part of the dissolved mineral matter, and the water would therefore be classed as carbonate.

The water is well adapted for industrial and domestic use. It could be used in boilers with little danger of causing scale, and if properly filtered would form an admirable municipal supply. At present the water is used for irrigation, hydraulic mining, power development, and for a public supply for the town of Oroville.

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[a] For data concerning gage heights and discharges see Water-Supply Papers U. S. Geol. Survey Nos. 81, 85, 100, 134, 177, and 213.

Mineral analyses of water from Feather River at Oroville.

[Parts per million unless otherwise stated.]

Date.		Turbidity.	Suspended matter.	Silica (SiO_2).	$Fe_2O_3+Al_2O_3$.	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle. (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Total dissolved solids.	Mean discharge.	
From—	To—														Acre-feet per day.	Cubic feet per second.
1906.	1906.															
Jan. 1	Jan. 9	.....	Trace.	.....	.....	17	7.0	.....	.....	0.0	87	12	5.9	138	2,560	1,291
Jan. 12	Jan. 20	.....	260	16	2.6	7.4	4.1	14	2.1	.0	45	12	4.4	96	72,463	36,534
Jan. 22	Jan. 29	.....	28	21	1.2	12	4.1	26	1.0	.0	63	13	5.9	104	17,645	8,896
Jan. 31	Feb. 9	.....	4	27	1.4	8.6	.....	.....	0.9	.0	61	10	6.9	88	10,505	5,296
Feb. 10	Feb. 17	.....	32	16	2.2	12	3.9	13	0.4	.0	56	8.1	8.8	100	17,383	8,764
Feb. 20	Mar. 1	.....	Trace.	17	3.8	9.7	3.9	5.5	2.3	.0	48	5.9	5.7	92	34,534	17,411
Mar. 2	Mar. 11	.....	24	18	1.8	9.7	5.1	4.1	1.8	.0	62	5.6	4.9	94	22,076	11,130
Mar. 13	Mar. 29	.....	108	20	7.6	12	6.0	7.6	1.2	.0	51	15	6.9	92	51,315	25,871
Apr. 1	Apr. 10	.....	74	15	4.2	13	7.2	11	2.8	.0	64	6.4	6.4	98	43,848	22,107
Apr. 11	Apr. 17	.....	74	12	4.6	13	7.9	7.6	1.6	.0	68	8.6	5.9	84	45,399	17,847
Apr. 18	May 10	.....	44	10	2.8	8.6	4.4	13	2.0	.0	48	6.9	7.8	78	37,430	18,871
May 11	May 20	.....	42	10	5.0	9.7	4.9	6.0	1.8	.0	37	5.8	4.5	72	31,215	15,738
May 21	May 31	.....	40	19	4.4	13	7.4	8.2	3.7	.0	42	17	4.9	84	32,502	16,386
June 1	June 10	.....	20	12	3.6	11	5.4	5.8	0.7	.0	39	7.4	5.7	66	34,506	17,397
June 11	June 20	.....	20	9.8	3.8	11	4.9	8.7	1.5	.0	41	7.4	4.9	70	29,050	14,646
June 21	June 30	.....	28	10	4.0	14	3.8	16	1.9	.0	40	6.8	5.1	72	18,606	9,380
					Fe.											
July 1	July 10	.....	12	13	.30	9.4	7.2	6.5		.0	48	14	5.6	90	13,432	6,772
July 11	July 20	.....	60	14	.05	12	4.6	9.6		.0	59	7.1	4.8	84	10,680	5,384
July 21	July 25	.....	42	16	.10	19	3.5	8.8		.0	69	4.8	4.8	84	8,037	4,556
Sept. 5	Sept. 10	.....	34	34	.30	11	2.6	21		.0	84	22	6.1	108	3,923	1,978
Sept. 11	Sept. 20	.....	20	23	.15	11	6.9	7.5		.0	76	6.3	6.9	116	3,919	1,976
Sept. 21	Sept. 29	.....	2	16	.23	18	7.3	18		.0	81	10	5.1	122	3,816	1,924
Oct. 1	Oct. 10	.....	20	15	.15	15	7.0	17		.0	86	7.1	5.1	132	3,808	1,920
Oct. 11	Oct. 20	.....	20	20	.10	17	6.3	19		.0	105	12	5.0	138	3,808	1,920
Oct. 21	Oct. 31	.....	32	15	.10	20	9.0	14		.0	96	16	6.6	120	3,808	1,920
Nov. 1	Nov. 10	.....	70	19	.15	15	5.8	13		.0	78	16	5.6	112	6,224	3,138
Nov. 11	Nov. 20	20	4	12	.30	16	6.2	15		.0	86	23	7.0	116	4,086	2,060
Nov. 21	Nov. 29	10	20	17	.10	16	5.9	16		.0	84	15	6.1	108	4,078	2,056
Dec. 2	Dec. 10	30	56	22	.20	22	7.7	29		.0	81	....	6.1	122	5,963	3,006
Dec. 11	Dec. 20	10	34	19	.20	20	6.8	17		.0	67	8.3	5.1	94	10,482	5,284
Dec. 21	Dec. 31	20	42	8.0	.12	14	4.4	12		.0	48	8.3	5.6	96	24,726	12,466
Mean		.....	41	16	[a].17	13	5.7	14		0.0	64	11	5.8	99	19,736	9,804
Percent of anhydrous residue		.....	.....	16.4	0.2	13.3	5.8	14.3		32.8	....	11.3	5.9	.....	.....	.....

[a] Mean of Fe values after July 1.

YUBA RIVER.

DESCRIPTION.

Yuba River, fourth in size in the Sacramento Valley, unites with Feather River at Marysville, 30 miles above its mouth. It drains about 1,357 square miles of the western slope of the Sierra Nevada, comprising portions of Sierra, Nevada, Plumas, and Yuba counties. The extreme length of its basin is about 71 miles; the extreme width is 36 miles.

For the lower 10 miles of its course in the foothills the bed of the river is badly clogged with débris from hydraulic mining camps and is held between levees which have been raised from year to year to meet the overflow caused by the filling up of the area between them. The channel of the river in the lower foothills has been filled with cobbles and bowlders to a depth of more than 100 feet. From the

foothills to the mouth of the river at Marysville the stream flows over a bed of gravel, sand, and clay recently built up from the mines above. The channels are irregular and change from winter to winter and sometimes during the summer.

The drainage basin may be subdivided into five small basins, namely: North Fork, 491.6 square miles in extent; Middle Fork, 218 square miles; South Fork, 360 square miles; Deer Creek, 89.6 square miles; and Dry Creek, 105.5 square miles. In addition to these an area of 92.5 square miles drains into the main stream just above the 100-foot contour. Dry Creek joins the river from the north just as it leaves the foothills; the other streams unite with it in the mountains.

In the western and lower portions of the drainage area are slates and kindred rocks, very much eroded, and merging into the gravel and alluvial deposits of the Great Valley of California. The rocks of the upper portions of the basin are principally lavas and granites, all deeply eroded. A stratum of serpentine traverses this basin in a direction generally parallel with the crest of the Sierra. It is intercepted by the North Fork at Goodyears Bar, by the Middle Fork at Moores Flat, and by the South Fork just east of Washington. This stratum is generally softer than adjoining strata, and through it the canyons of the various forks are upon lighter grades than immediately above and below and are generally much wider. It is of further interest because it forms the dividing line between the auriferous strata in the basin; west of it the mines are more extensive; east of it the gold-bearing rock occurs irregularly and is traced with difficulty.

The middle and upper portions of the basins of the three forks differ materially. The North Fork rises in a region of lavas which vary much in composition and hardness but which generally afford a deep soil for timber and shrub growth. The Middle Fork rises in similar lavas and in granite. The mean elevation of the crest of the Sierras at the heads of these forks is about 8,200 feet. The main and tributary streams fall rapidly and their canyons head well back into the mountains. The sides of these canyons are covered with timber and brush, which, with the deep soil, retain the moisture and feed numerous perennial springs. This condition is particularly noticeable on the North Fork. The mean annual precipitation upon the drainage areas of the North and Middle forks is about 54 inches. Warm rains and soft snow sometimes give a high flood run-off, but snow remains on the peaks until midsummer. The headwaters of the South Fork lie upon a broad granite surface into which the streams have not cut deeply until the main stream reaches a point 16 miles from the summit, where it drops rapidly into a deeply eroded canyon. This broad surface has been denuded by glacial action, and the harder nature of the granite has not permitted a deep soil

to form. The area is, therefore, less heavily timbered than the drainage areas of the other two forks. This topography gives a broader and more gently sloping surface than characterizes the headwaters of other Sierra Nevada streams. Over the surface are scattered nearly 100 glacial lakelets and valleys, affording many excellent reservoir sites which have been or are to be utilized. This elevated area receives a mean annual precipitation of 60 inches, most of which is in the form of snow. The melting of this snow maintains the discharge of the tributaries until June or July, and with the natural and artificial reservoirs, makes the South Fork of the Yuba a highly valuable and reliable source of supply.

The basin of the Yuba is not thickly populated, most of the towns being mining communities of between 100 and 200 inhabitants. The principal industries in the upper reaches are mining, lumbering, and stock raising. Irrigation headworks of considerable size are located in the foothills, and these supply water for agricultural purposes in the lower valleys.

CHARACTER OF WATER NEAR SMARTSVILLE.

Samples of water for this investigation were collected at the gaging station near Smartsville [a] by J. R. McKeel, the gage reader. The stream at this point is swift at all stages. Both banks are steep and rocky and are not subject to overflow. The bed of the stream is composed of gravel and sand and is constantly shifting.

Calcium, magnesium, and bicarbonates constitute the greater part of the mineral matter in solution, and the water would therefore be classed as carbonate. Suspended matter is high during periods of extreme flood, but is at all times coarse and could be readily removed by sedimentation or filtration.

The water of the Yuba is used in no manufacturing industries at the present time, although, like that of other Sierra streams, it is fitted for almost any industrial use if properly clarified.

[a] For data relative to gage heights and discharges for the years 1903 to 1906 see Water-Supply Papers U. S. Geol. Survey Nos. 100, 134, 177, and 213.

Mineral analyses of water from Yuba River at Smartsville.

[Parts per million unless otherwise stated.]

Date.		Suspended matter.	Silica (SiO_2).	$Fe_2O_3 + Al_2O_3$.	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Total solids.	Mean discharge.	
From—	To—													Acre-feet per day.	Cubic feet per second.
1906.	1906.														
Jan. 1	Jan. 10	124	18	2.4	11	4.6	26	3.2	0.0	63	18	6.4	110	1,111	560
Jan. 11	Jan. 20	.....	27	1.8	25	4.7	13	2.7	.0	69	23	8.6	106	35,958	18,129
Jan. 21	Jan. 30	248	17	.8	9.4	3.3	11	2.9	.0	46	20	3.9	62	8,946	4,510
Jan. 31	Feb. 9	172	18	3.0	14	4.8	6.6	.7	.0	44	23	4.9	106	4,471	2,254
Feb. 10	Feb. 19	298	13	2.6	10	3.4	5.2	1.9	.0	41	9.7	5.9	94	8,923	4,499
Feb. 20	Feb. 28	362	15	2.4	5.7	3.3	3.5	2.7	.0	36	7.1	6.3	56	16,287	8,211
Mar. 2	Mar. 11	326	13	3.0	8.3	4.4	5.2	1.0	.0	41	13	5.9	90	10,899	5,495
Mar. 12	Mar. 21	344	15	5.2	7.7	4.0	3.3	.4	.0	43	9.9	6.4	74	19,127	9,643
Apr. 1	Apr. 10	262	12	3.4	8.9	3.9	6.8	1.7	.0	33	8.7	3.9	64	20,559	10,365
Apr. 11	Apr. 20	234	7.2	4.0	7.7	4.5	8.7	2.2	.0	21	7.1	3.9	56	16,354	8,245
Apr. 21	Apr. 29	352	11	2.4	8.0	2.8	6.1	1.5	.0	33	7.9	4.9	70	15,273	7,700
May 3	May 10	290	15	3.0	8.9	3.4	6.6	1.3	.0	27	11	5.4	50	25,117	12,663
May 11	May 20	192	14	1.8	5.7	2.9	7.4	.7	.0	26	6.8	4.9	50	17,415	8,785
May 21	May 31	240	12	2.0	7.7	4.2	6.6	.6	.0	28	3.1	4.9	62	22,504	11,346
June 1	June 9	346	12	3.6	7.7	4.7	7.4	....	.0	28	9.7	4.9	62	24,850	12,528
June 11	June 19	230	12	4.8	8.9	6.3	6.6	1.7	.0	23	7.1	5.1	54	22,494	11,341
June 20	June 30	142	11	4.6	10	5.7	11	.5	.0	31	12	5.8	68	12,556	6,330
				Fe.											
July 2	July 10	126	12	0.30	7.7	3.8	8.4		.0	35	11	4.9	74	10,605	5,397
July 11	July 20	162	16	.15	6.9	2.8	7.3		.0	36	8.4	4.9	70	6,413	3,233
July 21	July 31	264	14	.10	11	3.1	9.1		.0	45	8.6	5.4	80	3,221	1,624
Aug. 1	Aug. 10	96	13	.15	18	5.0	11		.0	59	12	4.9	88	1,736	872
Aug. 11	Aug. 20	74	20	.20	23	5.1	10		.0	72	12	4.9	114	3,161	1,594
Aug. 21	Aug. 30	84	15	.20	18	4.5	12		.0	60	13	4.4	88	1,283	647
Sept. 1	Sept. 10	50	13	.13	23	4.7	13		.0	63	10	4.4	98	1,099	554
Sept. 11	Sept. 20	36	14	.30	20	5.4	14		.0	64	13	5.1	104	1,016	512
Sept. 21	Sept. 30	30	11	.15	17	4.9	12		.0	62	17	4.6	100	979	494
Oct. 1	Oct. 10	34	10	.05	23	3.8	9.6		.0	80	12	6.1	94	813	410
Oct. 11	Oct. 20	28	8.4	.10	21	5.2	10		.0	76	15	5.6	100	801	404
Oct. 21	Oct. 31	18	9.6	.25	18	4.6	12		.0	73	13	5.0	118	785	396
Nov. 1	Nov. 10	240	13	.75	12	4.9	16		.0	58	19	6.6	110	2,284	1,152
Nov. 11	Nov. 20	18	14	.25	15	4.9	10		.0	63	23	7.1	106	1,103	556
Nov. 21	Nov. 30	2	13	.10	20	5.4	14		.0	67	22	7.1	112	1,099	554
Dec. 1	Dec. 10	136	12	.07	18	4.5	8.0		.0	59	15	6.1	100	1,756	885
Dec. 11	Dec. 20	386	10	.30	11	3.9	8.7		.0	46	19	6.1	84	8,966	4,520
Dec. 21	Dec. 31	536	11	.25	8.6	3.5	10		.0	33	10	6.1	70	13,542	6,827
Mean		191	14	[a].21	13	4.3	10		.0	48	13	5.5	84	9,814	4,950
Per cent of anhydrous residue..		.....	16.7	0.2	15.5	5.1	11.9		28.6	.....	15.5	6.5	.....	.....	.....

[a] Mean of Fe values after July 1.

AMERICAN RIVER.

DESCRIPTION.

American River rises in the high Sierra at an elevation of about 9,000 feet above sea level and flows generally westward, emptying into Sacramento River just above the city of Sacramento. The river is 80 miles long and drains about 2,000 square miles of territory lying between the basins of Bear and Yuba rivers on the north and Cosumnes River on the south. The higher portions of the basin are composed of the characteristic granite of the Sierra, with fair soil covering and good timber growth. The river has three main tributaries—the North, Middle, and South forks—and many smaller ones.

The territory drained by the American is not thickly settled, few of the towns having a population greater than 1,000. The principal industries are mining in the upper reaches and on the smaller tributaries and agriculture in the lower valleys. In the past much hydraulic mining has been carried on, and at some places the stream bed has been filled with quantities of débris.

CHARACTER OF RIVER WATER AT FAIROAKS.

Samples of water for this investigation were collected by the gage reader at Fairoaks Bridge,[a] about 18 miles above the mouth of the river. The channel at this point is straight for 400 feet above and below the station. The bed of the stream is composed of gravel and is subject to slight changes at times of high water. At ordinary stages the river is about 210 feet wide and 4 feet deep.

During the winter months the flow of the stream is rather torrential, because of the large areas of barren and sparsely timbered country in the lower portions of the watershed, and the river carries a large quantity of suspended matter, much of which is deposited in a short time if the water is allowed to remain at rest. Later in the season another period of high water is caused by the melting snow from the mountains; at this time the water carries considerable suspended matter, generally finer than that of the winter season. This suspended material does not settle readily from the water, but remains to impart a decided turbidity for a long time.

As calcium, magnesium, and bicarbonates constitute by far the greater part of its dissolved material, the water from American River would be classed as carbonate. The total amount of dissolved mineral matter is not high, although it is somewhat greater than that in more southerly streams from the Sierra.

The water of this river is used for mining, power development, irrigation, and, in a small way, for the municipal supply of a few towns along its course, but it is not at present employed in manufactures, although it would be suitable for use in almost any industry if the suspended matter were removed by sedimentation or filtration.

[a] For gage heights and discharge data for this stream see Water-Supply Papers U. S. Geol. Survey Nos. 134, 177, and 213.

Mineral analyses of water from American River at Fairoaks.

[Parts per million unless otherwise stated.]

Date.		Suspended matter.	Silica (SiO_2).	$Fe_2O_3+Al_2O_3$.	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Total solids.	Mean discharge.	
From—	To—													Acre feet per day.	Cubic feet per second.
1906.	1905.														
Jan. 1	Jan. 10	98	25	1.4	17	6.3	17	1.0	0.0	86	9.4	11	102	714	360
Jan. 11	Jan. 20	610	29	.2	8.6	3.7	12	.0	.0	45	12	4.4	64	33,361	16,819
Jan. 21	Jan. 29	56	21	.4	9.7	6.0	11	2.8	.0	38	23	6.4	136	9,041	4,558
Jan. 31	Feb. 9	Trace.	20	1.2	8.3	2.5	8.2	.6	.0	40	12	8.8	108	4,539	2,288
Feb. 10	Feb. 19	.....	17	2.6	8.0	3.3	4.2	.4	.0	35	6.8	6.9	....	10,102	5,093
Feb. 20	Mar. 1	240	17	2.4	6.3	3.2	8.5	1.8	.0	42	7.7	6.7	82	19,881	10,023
Mar. 2	Mar. 11	152	14	3.4	11	5.1	5.7	1.0	.0	64	14	8.6	86	15,547	7,838
Mar. 12	Mar. 21	278	17	3.8	8.6	3.4	5.5	....	.0	34	11	7.8	74	28,864	14,552
Mar. 22	Mar. 31	400	17	3.0	8.0	4.6	11	2.7	.0	33	6.8	7.8	92	39,467	19,898
Apr. 1	Apr. 10	234	16	4.0	8.3	4.2	8.8	1.8	.0	31	7.1	3.9	62	25,165	12,687
Apr. 16	Apr. 17	.....	.....	.....	.....	.....	.....	.....	.0	29	.....	4.4	....	24,000	12,100
May 1	May 10	286	11	3.0	6.9	4.0	9.3	1.2	.0	25	8.6	3.9	48	33,452	16,865
May 11	May 18	86	9.4	3.0	6.0	2.8	6.2	1.3	.0	20	8.4	3.9	56	27,161	13,694
May 21	May 28	212	19	3.6	5.9	6.1	8.5	1.4	.0	21	3.3	4.4	58	28,088	14,161
May 29	June 10	76	10	4.8	8.3	2.8	8.2	.6	.0	24	7.4	4.2	62	33,551	16,915
June 11	June 20	116	12	5.0	9.1	6.0	4.7	1.3	.0	25	7.3	4.9	66	34,886	17,588
June 21	June 30	142	14	4.0	6.9	2.1	11	....	.0	19	6.8	3.7	56	26,850	13,537
July 1	July 10	116	.....	.....	.....	.....	.....	.....	.....	26	.....	3.4	54	21,110	10,643
				Fe.											
July 23	July 30	68	15	.30	7.4	2.7	7.4		.0	30	9.2	5.6	72	5,558	2,802
Aug. 1	Aug. 9	46	21	.10	12	4.4	9.9		.0	40	13	4.8	74	3,165	1,596
Aug. 12	Aug. 20	46	19	.40	8.5	3.7	11		.0	37	11	4.8	74	1,823	919
Aug. 21	Aug. 30	32	14	.40	14	4.5	10		.0	43	15	4.9	80	1,285	648
Sept. 2	Sept. 10	48	13	.30	13	4.7	9.4		.0	44	13	5.8	80	998	503
Sept. 11	Sept. 20	70	15	.40	16	4.6	15		.0	53	12	7.1	104	864	436
Sept. 21	Sept. 30	58	14	.30	12	4.1	13		.0	48	12	7.1	92	702	354
Oct. 1	Oct. 10	72	14	.30	15	4.6	20		.0	61	13	8.1	96	686	346
Oct. 11	Oct. 20	122	17	.30	14	5.4	21		.0	59	13	7.6	98	627	316
Oct. 21	Oct. 31	92	18	.35	13	5.4	13		.0	58	13	7.1	114	696	351
Nov. 1	Nov. 10	164	19	.70	16	5.3	.....		.0	50	14	9.1	96	1,515	764
Nov. 11	Nov. 20	76	24	.80	11	4.8	14		.0	48	22	8.1	100	966	487
Nov. 21	Nov. 30	108	16	.40	17	5.3	9.7		.0	55	24	7.1	98	892	450
Dec. 1	Dec. 10	264	18	.7	11	4.9	10		.0	47	13	6.6	100	1,202	606
Dec. 11	Dec. 20	158	11	.30	12	5.1	10		.0	46	22	10	98	8,569	4,320
Dec. 21	Dec. 31	140	15	.20	10	4.6	17		.0	37	12	5.6	80	12,921	6,514
Mean		146	17	a.39	11	4.4	11		0.0	41	12	6.3	83	13,478	6,795
Per cent of anhydrous residue		.....	20.7	0.5	13.4	5.3	13.4		24.4	.....	14.6	7.7	....	.....	.....

a Mean of Fe values after July 1.

SAN JOAQUIN VALLEY.

DESCRIPTION.

San Joaquin Valley proper and the Tulare Valley are so closely related and so merge into each other that they may be considered together. A low alluvial divide scarce serves to separate the two, so that, although at times of insufficient rainfall they form two distinct drainage areas, at other times the waters of Tulare Valley drain through Tulare Lake and Kings River into the San Joaquin.

The basin is in general a southern complement of the Sacramento, being bounded on the west by the Coast Range, on the east by the Sierra Nevada, and on the south by the Tehachapi Mountains. The total length of the valley is about 270 miles and its area is approximately 15,000 square miles. Owing to the great aridity of the

eastern slopes of the Coast Range practically no streams flow into the valley from the west, but from the east several large rivers join the axial San Joaquin to form the second most important river system in the State. As a result of the great drainage from the east and the slight drainage from the west the San Joaquin has been gradually pushed westward by the deposition of detritus along the banks of the eastern tributaries which have built large, gently sloping fans across the valley.

SAN JOAQUIN RIVER.

DESCRIPTION.

San Joaquin River drains the western slope of the Sierra Nevada between Merced River on the north and Kings River on the south, the crest of its divide lying at an elevation of 13,000 to 14,000 feet above sea level in the vicinity of Mount Lyell and Mount Goddard. The river has numerous tributaries in this part of its drainage basin, many of which rise at high elevations.

The bed rock is granite, which in the upper reaches is bare and sharply marked by glacial action. The middle reaches are well timbered, the timber diminishing in the lower foothills as the stream approaches the valley, where the soil is well covered with brush and grass. The precipitation is largely in the form of snow on the higher elevations, which melts slowly and maintains a fairly constant stream flow throughout the season. Numerous small lakes also aid in equalizing the flow.

As the stream flows through the mountains its course is southwestward; as it reaches the valley it turns sharply to the northwest and flows along the axis of the valley. In this lower part of its course its fall is very slight, and the river is navigable for 100 miles or more from its mouth.

From its source in the high Sierra to the point where it joins the Sacramento at Suisun Bay the San Joaquin is about 200 miles long. It receives the discharges of all the Sierra streams south of the Mokelumne and from all the smaller creeks draining from the eastern slope of the Coast Range between San Francisco Bay and the Tehachapi. The rivers flowing from the Sierra to the San Joaquin run in a general southeasterly direction; the few creeks coming from the Coast Range flow northwestward. A list of the more important tributaries follows.

Principal tributaries of San Joaquin River.

From the west.

- Kings River
  - North Fork.
  - Middle Fork.
  - South Fork.
- Tule River.
- Kaweah River.
- Kern River.

From the east.

- Mokelumne River.
  - Cosumnes Creek.
- Calaveras River.
- Stanislaus River
  - North Fork.
  - Middle Fork.
  - South Fork.
- Tuolumne River
  - North Fork.
  - Middle Fork.
  - South Fork.
  - Eleanor Creek.
- Merced River.
  - Yosemite River.
  - Tanaya Creek.
- Chowchilla River.
- Fresno River.

Lumbering and mining are carried on in the upper part of the drainage basin. In the valley agriculture is the principal industry, and much fruit is produced in this section of the State. Grain is raised on the flat lands along the river bottoms. Water for irrigation is obtained from the Sierra streams.

CHARACTER OF WATER NEAR LATHROP.

Samples of water for this investigation were collected from the river at a point near the Southern Pacific Railroad drawbridge, between Lathrop and Tracy. The river at this point is sluggish at low-water stages, but during high water it overflows the levees that are built to confine it to its channel and floods the country for miles around. At the drawbridge the river is more or less influenced by the tides at periods of very low water. No gage records are available.

The chemical investigation shows the water to be of good quality, as regards dissolved mineral matter. It is, however, turbid at all seasons of the year, owing to the exceedingly fine silt which is brought down from the hills on the west side of the valley.

The presence near the river of so many large towns, sewage from which may contaminate the water, is sufficient to condemn the river as a source of public supply. There is no reason to believe, however, that the water could not be made pure and wholesome at slight expense by proper filtration and purification.

Mineral analyses of water from San Joaquin River at Lathrop.

[Parts per million unless otherwise stated.]

Date.		Turbidity.	Suspended matter.	Silica (SiO_2).	$Fe_2O_3+Al_2O_3$.	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3)	Sulphate radicle (SO_4).	Chlorine (Cl).	Total solids.
From—	To—													
1906.	1906.													
Jan. 1	Jan. 10	.....	82	27	3.0	32	12	55	0.6	0.0	118	59	72	260
Jan. 11	Jan. 20	.....	264	22	2.4	20	7.9	30	2.9	.0	76	46	39	186
Jan. 21	Jan. 30	.....	160	21	1.2	10	5.0	22	4.2	.0	50	17	13	88
Jan. 31	Feb. 9	.....	16	22	2.4	9.1	8.7	38	2.7	.0	85	36	20	204
Feb. 10	Feb. 19	.....	84	17	1.6	15	5.9	17	1.3	.0	61	18	24	140
Feb. 20	Mar. 1	.....	130	21	3.8	14	5.9	16	1.9	.0	57	15	12	122
Mar. 2	Mar. 11	.....	128	20	6.0	13	6.4	11	1.3	.0	63	16	14	126
Mar. 12	Mar. 21	.....	48	16	5.2	16	7.4	5.2	1.2	.0	64	22	15	138
Mar. 22	Mar. 31	.....	78	22	4.0	15	6.5	8.7	2.0	.0	51	15	13	108
Apr. 1	Apr. 10	.....	10	20	4.0	36	7.8	15	4.4	.0	71	15	15	186
Apr. 11	Apr. 20	.....	76	16	2.0	11	5.2	13	2.0	.0	51	9.1	9.3	84
Apr. 21	Apr. 27	.....	50	11	4.8	9.7	5.3	9.6	1.3	.0	38	11	6.9	84
May 3	May 10	.....	58	10	2.4	8.6	2.9	8.7	2.1	.0	36	6.6	7.8	76
May 11	May 20	.....	18	10	3.8	9.1	3.5	5.5	2.2	.0	26	9.1	7.9	60
May 21	May 30	.....	32	10	2.0	8.9	3.6	6.9	3.7	.0	30	8.7	8.8	60
May 31	June 10	.....	26	10	3.0	8.3	5.7	8.2	1.0	.0	38	9.7	9.6	68
June 11	June 20	.....	8	8.0	3.2	8.8	4.6	10	.9	.0	29	12	7.8	72
June 21	June 30	.....	6	14	4.8	11	6.4	6.2	.8	.0	30	14	7.8	70
					Fe.									
July 1	July 7	.....	4	9.4	.20	8.0	6.7	9.5		.0	33	9.2	6.8	70
July 11	July 20	.....	32	25	.20	8.6	2.9	6.4		.0	42	11	7.8	74
July 21	July 30	.....	68	11	.10	8.0	3.2	12		.0	40	6.8	7.8	80
Aug. 1	Aug. 10	.....	42	11	.15	16	4.6	15		.0	38	8.9	7.8	82
Aug. 11	Aug. 20	.....	92	9.8	.27	11	3.9	12		.0	38	11	8.7	72
Aug. 21	Aug. 30	.....	58	9.8	.30	11	4.5	15		.0	44	16	11	94
Aug. 31	Sept. 9	.....	.....	17	.25	19	6.8	20		.0	62	20	28	.....
Sept. 10	Sept. 19	.....	38	13	.20	25	8.5	27		.0	72	30	40	182
Sept. 21	Sept. 30	.....	24	17	.20	29	12	37		.0	88	42	63	252
Oct. 1	Oct. 10	.....	38	18	.15	36	13	64		.0	102	59	83	328
Oct. 11	Oct. 20	.....	26	19	.10	41	16	68		.0	123	60	92	358
Oct. 21	Oct. 31	.....	32	17	.10	33	16	56		.0	122	60	86	324
Nov. 1	Nov. 10	.....	12	17	.7	32	14	52		.0	117	51	78	332
Nov. 11	Nov. 20	40	34	17	.30	28	12	52		.0	110	47	69	282
Nov. 21	Nov. 30	20	16	19	.20	30	14	48		.0	109	62	74	320
Dec. 1	Dec. 10	30	28	18	.25	31	13	68		.0	111	55	78	310
Dec. 11	Dec. 20	200	194	15	.40	22	8.8	25		.0	73	38	29	182
Dec. 21	Dec. 31	20	78	15	.15	21	6.4	26		.0	73	23	24	158
Mean		.....	60	16	[a].23	18	8.0	27		.0	66	26	30	161
Per cent of anhydrous residue		.....	.....	10.1	0.1	11.4	5.1	17.1		20.9	.....	16.4	18.9	.....

[a] Mean of Fe values after July 1.

Mineral analyses of water from San Joaquin River at Lathrop—Continued.

Date.		Turbidity.	Suspended matter.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle. (NO_3).	Chlorine (Cl).	Total solids.
From—	To—													
1907. Dec. 31	1908. Jan. 9	45	59	24	0.40	19	5.8	14	0.0	61	31	0.84	13	147
1908.														
Jan. 10	Jan. 19	60	37	20	.38	16	8.7	25	.0	57	36	2.4	22	155
Jan. 20	Jan. 29	80	84	22	.17	16	7.9	25	.0	59	29	1.4	22	146
Jan. 30	Feb. 8	50	91	23	.52	17	5.5	26	.0	59	29	1.2	22	149
Feb. 9	Feb. 18	70	193	21	.48	15	6.7	26	.0	61	27	.80	31	145
Feb. 19	Feb. 28	40	.....	23	.15	16	8.8	33	.0	73	34	.88	31	172
Feb. 29	Mar. 9	65	57	21	.25	14	9.8	21	.0	66	28	.50	23	138
Mar. 10	Mar. 19	60	66	25	.39	14	6.3	24	.0	63	26	.34	17	124
Mar. 20	Mar. 29	40	61	23	.55	8.4	3.1	14	.0	42	17	1.4	9.0	94
Mar. 30	Apr. 8	50	56	20	.38	14	6.4	17	.0	37	27	1.1	19	112
Apr. 9	Apr. 18	30	78	13	.18	10	3.3	15	.0	37	25	1.2	13	84
Apr. 19	Apr. 28	65	80	14	.35	6.8	2.3	8.2	.0	29	16	1.2	6.0	62
Apr. 29	May 8	100	92	12	.45	6.6	3.1	6.1	.0	22	19	Tr.	4.0	52
May 9	May 18	35	40	14	.30	5.5	2.0	6.5	.0	26	14	1.7	5.0	58
May 19	May 28	40	51	17	.30	8.6	3.1	5.5	.0	32	14	.78	6.0	63
May 29	June 7	35	36	13	.25	6.0	2.4	8.0	.0	27	15	1.3	4.5	58
June 8	June 17	30	42	12	.32	6.8	2.8	6.2	.0	29	13	.92	6.1	56
June 18	June 27	25	52	11	.21	7.8	2.9	12	.0	32	15	.52	11	66
June 28	July 7	30	36	16	.20	20	7.2	17	.0	55	24	1.4	16	131
July 8	July 17	6	.....	15	.20	17	4.4	21	.0	53	21	.35	28	125
July 18	July 27	30	29	23	.33	21	11	34	.0	76	30	.36	49	203
July 28	Aug. 6	15	18	15	.15	29	15	52	.0	98	51	2.0	77	286
Aug. 7	Aug. 16	7	.....	16	.08	25	16	68	.0	107	58	.....	103	357
Aug. 17	Aug 26	12	18	16	.28	33	18	70	.0	116	59	2.0	98	347
Aug. 27	Sept. 5	22	25	19	.20	39	20	72	.0	128	70	1.0	108	396
Sept. 6	Sept. 15	6	.....	25	.20	40	21	77	.0	139	73	.64	116	416
Sept. 16	Sept. 25	30	37	20	.29	37	20	70	.0	126	72	.36	119	391
Sept. 26	Oct. 5	25	34	19	.10	34	18	58	.0	123	67	Tr.	87	364
Oct. 6	Oct. 15	10	.....	24	.15	37	19	68	.0	124	67	.94	103	373
Oct. 16	Oct. 25	40	30	19	.12	25	14	43	.0	98	61	.86	73	297
Oct. 26	Nov. 4	35	26	18	.10	25	14	49	.0	95	52	.68	69	268
Nov. 5	Nov. 14	9	.....	17	.18	29	15	56	.0	104	53	.70	80	302
Nov. 15	Nov. 24	Tr.	.....	19	.75	31	18	73	.0	107	70	1.4	97	372
Nov. 25	Dec. 4	5	.....	20	.28	28	15	60	.0	105	57	1.0	79	324
Dec. 5	Dec. 14	26	16	17	.38	25	15	49	.0	85	55	2.1	59	256
Dec. 15	Dec. 24	18	15	27	.50	21	13	46	.0	90	44	1.7	54	234
Dec. 25	Dec. 31	25	.....	20	.50	23	14	49	.0	90	44	1.5	58	247
Mean		34	52	19	.30	20	10	36	.0	74	39	1.0	47	205
Percent of anhydrous residue		.....	.....	9.1	0.1	9.6	4.8	17.3	17.3	.....	18.7	0.5	22.6	.....

MOKELUMNE RIVER.

DESCRIPTION.

Mokelumne River rises on the western slope of the Sierra Nevad in about the east central part of the State. It flows generally west ward to southwestward and empties into the series of sloughs nea the confluence of San Joaquin and Sacramento rivers. The drainag basin comprises about 657 square miles of territory, heading we back toward the crest of the Sierra at an elevation of 8,000 feet abov sea level.

The bed rock is granite, with good soil covering and heavy timbe growth in the middle and upper portions of the basin; in the lowe portions the slopes are less rugged, the vegetation is brush and sca tered oak timber, and there are large areas of cultivated land and pa ture. Numerous small glacial lakes and moraines occur in the uppe reaches of the basin. On the upper levels the precipitation is partl in the form of snow, which melts in the early spring, causing th greatest stream discharge to come during the months of April, Ma and June. The river is diverted at several points for the purpose of mining and power development, but the diversions have no appre ciable effect on the discharge.

CHARACTER OF RIVER WATER NEAR CLEMENTS.

Samples of water for this investigation were collected by the gag reader at the station near Clements.[a] The stream at this point straight and the lower of its banks is liable to overflow at high stage The bed is composed of gravel and is subject to slight change.

Except during periods of extremely high water the Mokelumn carries little suspended matter, and even this is such as can be re moved easily by filtration.

The water may be classed as carbonate, for bicarbonates, calciun and magnesium constitute the greater part of the dissolved miner matter. Total solids are not high, showing that the water is fitte for almost any industrial use. It should give no trouble in boiler even without preliminary treatment, and if filtered should furnish satisfactory domestic supply.

[a] For data regarding gage heights and discharge see Water-Supply Papers U. S. Geol. Survey Nos. 1 177, and 213.

Mineral analyses of water from Mokelumne River at Clements.

[Parts per million unless otherwise stated.]

Date.		Suspended matter.	Silica (SiO_2).	$Fe_2O_3+Al_2O_3$.	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Total solids.	Mean discharge.	
From—	To—													Acre-feet per day.	Cubic feet per second.
1906.	1906.														
Jan. 1	Jan. 10	126	25	1.6	25	6.7	23	0.0	0.0	84	24	19	126	122	61.5
Jan 11	Jan. 20	504	22	5.0	23	3.4	16	2.3	.0	45	19	7.6	70	4,580	2,309
Jan. 21	Jan. 30	.....	19	2.6	12	3.1	.....	2.3	.0	40	10	7.4	.....	1,345	678
Jan. 31	Feb. 9	66	22	2.2	13	4.0	7.6	1.0	.0	40	17	8.8	86	742	374
Feb. 10	Feb. 19	46	17	2.0	10	3.0	13	2.0	.0	47	11	9.8	84	1,333	672
Feb. 20	Mar. 1	46	16	2.4	9.1	3.2	9.9	.9	.0	41	11	7.5	86	2,713	1,368
Mar. 2	Mar. 11	.....	16	2.2	9.1	2.7	5.2	2.4	.0	40	8.7	8.7	.....	2,050	1,034
Mar. 12	Mar. 21	92	17	3.0	9.4	3.8	6.9	2.6	.0	43	14	8.8	86	4,562	2,300
Mar. 22	Mar. 31	126	11	6.0	11	3.8	7.9	2.5	.0	36	8.7	7.8	74	8,678	4,375
Apr. 1	Apr. 10	84	15	3.0	7.1	3.2	9.6	1.5	.0	35	6.4	4.9	70	5,725	2,886
Apr. 11	Apr. 20	60	7.6	3.8	7.7	4.4	5.7	1.7	.0	28	4.6	3.9	52	5,500	2,773
Apr. 21	Apr. 30	28	13	8.4	17	7.2	6.9	1.2	.0	24	11	5.9	46	6,276	3,164
May 1	May 10	60	11	2.6	6.6	1.8	6.0	1.7	.0	24	7.9	3.9	54	10,747	5,418
May 11	May 20	54	11	2.4	7.2	2.7	5.8	2.0	.0	24	5.3	5.9	42	9,320	4,699
May 21	May 30	40	7.2	2.0	6.0	2.7	5.5	.9	.0	22	8.4	5.1	46	8,192	4,130
May 31	June 10	28	8.8	2.6	7.4	4.0	6.8	1.3	.0	25	12	4.1	52	9,892	4,987
June 11	June 19	52	9.0	4.6	6.0	5.3	5.4	1.0	.0	17	8.1	4.4	46	14,457	7,288
June 21	June 30	66	11	4.0	6.3	1.8	9.0	.....	.0	17	5.8	3.9	30	11,275	5,684
				Fe.											
July 2	July 10	56	17	.10	8.0	4.2	14		.0	22	4.9	4.8	56	12,081	6,091
July 11	July 20	74	20	.10	9.7	3.7	18		.0	39	8.6	6.7	56	6,835	3,446
July 21	July 30	86	8.4	.10	6.9	2.0	8.0		.0	25	4.8	5.8	44	2,923	1,474
Aug. 1	Aug. 10	42	11	.10	22	4.4	19		.0	43	14	5.8	78	1,111	562
Aug. 11	Aug. 20	60	13	.10	14	4.0	14		.0	40	12	5.8	78	653	329
Aug. 22	Aug. 30	58	12	.15	13	3.8	10		.0	44	14	7.7	76	392	198
Sept. 1	Sept. 10	42	9.4	.10	15	3.9	9.8		.0	47	13	6.3	74	378	191
Sept. 13	Sept. 20	52	19	.23	19	5.9	13		.0	62	18	12	118	394	199
Sept. 21	Sept. 30	50	11	.20	13	4.1	39		.0	46	13	8.1	90	384	194
Oct. 1	Oct. 8	68	12	.10	17	3.9	18		.0	63	10	9.1	97	351	177
Oct. 11	Oct. 20	68	9.2	.10	16	2.0	10		.0	49	11	7.6	70	382	193
Oct. 21	Oct. 31	90	9.6	.13	15	3.6	14		.0	49	16	6.6	78	384	194
Nov. 1	Nov. 10	88	13	.30	11	3.2	14		.0	65	12	6.6	84	603	304
Nov. 11	Nov. 20	64	16	1.00	14	5.2	13		.0	63	13	8.6	112	447	225
Nov. 21	Nov. 30	62	9.6	.07	17	4.9	14		.0	62	17	8.6	98	429	216
Dec. 1	Dec. 10	128	11.2	.20	21	4.1	13		.0	58	15	7.6	96	425	214
Dec. 11	Dec. 20	190	16	.15	15	4.5	14		.0	48	13	9.7	118	2,256	1,138
Dec. 21	Dec. 31	88	12	.05	11	4.0	15		.0	38	14	8.2	86	2,457	1,239
Mean.....		84	14	[a].18	12	3.8	13		.0	42	12	7.3	75	3,900	1,883
Per cent of anhydrous residue...		.....	16.8	0.2	14.4	4.6	15.6		25.2	.....	14.4	8.8	.....	.....	.....

[a] Mean of Fe values after July 1.

STANISLAUS RIVER.

DESCRIPTION.

Stanislaus River heads well back into the higher portion of the Sierra Nevada, at altitudes of 10,000 to 12,000 feet above sea level, and drains a portion of its western slope lying between the basins of Mokelumne River on the north and the Tuolumne on the south. Its course is in general southwestward, and it joins the San Joaquin in the vicinity of Vernalis, about halfway between Modesto and Stockton. In the upper parts of the basin the river has many tributaries which rise in small glacial lakes.

The topography of the drainage area is rough and broken, with high mountain peaks. The bed rock is granite, which is bare and destitute of timber growth above the elevation of 8,000 feet except about the lakes and on the moraines. In the middle parts of the basin the soil is deep and the growth of timber is good. Precipitation is largely in the form of snow, which remains on the higher elevations well into the summer months, and which produces on melting a fairly constant stream flow throughout the season.

The principal industries are mining in the higher areas and raising of grain and fruit in the lower valleys. Water for irrigation is taken from the river at points above Knights Ferry, to be used in the region between Knights Ferry and Stockton.

CHARACTER OF WATER.

Samples of water for this investigation were collected at the gaging station at Knights Ferry[a] by the gage reader during the first part of the year 1906. Results for that period showed such close resemblance between the waters of Tuolumne, Merced, and Stanislaus rivers that the sampling stations on the Merced and Stanislaus were discontinued and the results obtained with the Tuolumne were regarded as typical for the surface waters of this section of the State.

The stream at the sampling station flows between low banks of cemented gravel. The bed is composed of sand and gravel and is liable to slight change.

The results of the analytical study are presented in the accompanying analyses.

The chemical analyses show that the water would be well adapted to almost any industry if the suspended matter were removed, and proper clarification would fit it for use in boilers without further treatment. The large number of settlements in the basin make this water unsafe for domestic purposes without purification, and except in irrigation enterprises and power development, little use is made of it.

[a] For data regarding gage heights and discharge see Water-Supply Papers U. S. Geol. Survey Nos. 81, 100, 134, 177, and 213.

Mineral analyses of water from Stanislaus River at Knights Ferry.

[Parts per million unless otherwise stated.]

Date.		Suspended matter.	Silica (SiO_2).	$Fe_2O_3+Al_2O_3$.	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Total solids.	Mean discharge, including canal.		Mean discharge without canal.	
From—	To—													Acre-feet per day.	Cubic feet per second.	Acre-feet per day.	Cubic feet per second.
1906.	1906.																
Jan. 1	Jan. 10	86	9.6	0.6	23	7.4	15	0.1	0.0	106	22	16	138	831	419	754	380
Jan. 11	Jan. 20	642	25	1.2	16	4.7	12	....	.0	63	14	5.4	116	10,872	5,481	10,774	5,432
Jan. 21	Jan. 30	118	20	1.4	14	4.7	37	2.7	.0	61	8.6	4.4	76	3,278	1,653	3,254	1,641
Jan. 31	Feb. 9	76	22	1.4	11	14	14	1.9	.0	61	15	5.9	126	2,294	1,157	2,169	1,094
Feb. 10	Feb. 19	190	18	2.2	17	5.7	6.8	.4	.0	61	14	6.2	118	3,526	1,778	3,383	1,706
Feb. 20	Mar. 1	118	19	1.8	16	5.8	4.3	1.3	....	....	8.4	....	98	6,409	3,231	6,328	3,190
Mar. 2	Mar. 11	124	16	3.6	....	5.7	6.5	1.3	.0	64	11	5.3	114	5,138	2,590	4,048	2,545
Mar. 12	Mar. 20	126	17	3.8	13	5.3	4.8	3.4	.0	60	11	9.8	114	9,387	4,733	10,317	5,201
Mar. 22	Mar. 31	574	20	3.4	12	5.5	9.0	1.4	.0	55	8.1	5.4	120	17,106	8,624	17,058	8,600
Apr. 1	Apr. 10	84	13	3.2	11	5.2	10	1.9	.0	55	6.4	3.9	76	9,814	4,948	9,755	4,918
Apr. 11	Apr. 20	94	10	2.4	8.6	5.0	3.6	1.1	.0	38	6.4	4.2	68	10,420	5,253	10,245	5,165
Apr. 21	Apr. 28	94	7.0	3.8	....	4.9	11	2.6	.0	34	6.4	3.7	54	12,164	6,133	11,949	6,024
May 2	May 10	80	11	3.2	7.1	3.1	5.8	1.0	.0	30	17	3.9	58	18,602	9,378	18,376	9,264
May 11	May 20	38	13	2.0	5.7	3.3	8.8	1.3	.0	30	23.4	4.5	58	16,884	8,512	16,649	8,394
May 21	May 30	58	11	2.4	6.0	3.6	8.8	1.2	.0	34	9.6	5.4	68	14,026	7,071	13,779	6,947
May 31	June 10	16	7.6	3.0	8.0	4.6	7.3	....	.0	28	8.2	4.4	66	15,178	7,652	14,909	7,516
June 11	June 20	86	8.8	2.8	7.1	3.5	7.4	0.8	.0	25	9.2	4.9	44	23,405	11,800	23,147	11,670
June 21	June 30	66	8.8	3.8	8.1	3.1	9.0	.6	.0	28	8.2	4.9	48	16,560	8,349	16,376	8,256
				Fe.													
July 1	July 10	78	7.0	.20	8.3	4.6	9.4		.0	26	9.4	3.9	46	15,989	8,061	15,716	7,923
July 11	July 20	48	11	.10	7.1	3.0	7.4		.0	33	6.8	4.1	68	9,506	4,793	9,304	4,691
July 21	July 31	138	13	.30	9.7	3.2	9.1		.0	38	6.8	4.9	74	5,955	3,002	5,721	2,884
Mean		140	14	[a].20	11	5.0	11		.0	46	11	5.6	83	10,826	5,453		
Percent of anhydrous residue			17.3	0.3	13.6	6.2	13.6		28.5		13.6	6.9					

[a] Mean of Fe values after July 1.

TUOLUMNE RIVER.

DESCRIPTION.

Tuolumne River rises on the western slope of the Sierra Nevada and drains the country between Stanislaus River on the north and Merced River on the south, flowing in a general west to southwesterly course, and emptying into the San Joaquin near Modesto. The country throughout the basin is rough and rugged, especially along the main river, which cuts through solid granite, with high precipitous cliffs on both sides. This stream drains the northern portion of the Yosemite National Park, within which lies the Grand Canyon of the Tuolumne and the Hetch Hetchy Valley.

The bed rock of the basin is granite, which on the higher elevations is bare and glaciated. Along the middle reaches of the river the soil covering is good, with a heavy growth of pine, fir, cedar, and kindred trees. On the lower reaches there is a good covering of brush, which diminishes in the foothills as the stream approaches the San Joaquin Valley. This part of the basin has a light soil covering, with growth of grass which is used for pasturage. In the upper portions of the

basin are several glacial lakes, some of the larger offering exceptional advantages for the construction of storage reservoirs.

Several diversions are made from the river for purposes of irrigation. At Lagrange, where the stream leaves the foothills, are the head works of the Turlock and Modesto irrigation canals which supply water to the valley regions around Modesto. The main industries of this region are mining, stock raising, and agriculture. Water from the river is used for no other purpose until it reaches the valley, where some is used in the town of Modesto as a domestic supply.

CHARACTER OF WATER AT LAGRANGE.

Samples of water for this investigation were collected at the gaging station at Lagrange[a] by the gage reader. The river at this point is swift, shallow, and wide at high stages, and very sluggish during periods of low water. The bed of the stream is composed of coarse gravel and is fairly permanent.

The results of the investigation are shown by the accompanying analyses.

The water is well adapted to almost any industrial use without previous treatment. Owing to the comparatively large population in the lower drainage area the water would be unfit for domestic use unless diverted from the stream far above all points of possible contamination or unless proper means should be employed for its purification.

Mineral analyses of water from Tuolumne River at Lagrange.

[Parts per million unless otherwise stated.]

Date.		Suspended matter.	Silica (SiO_2).	$Fe_2O_3+Al_2O_3$.	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Total solids.	Mean discharge, including canals.		Mean discharge, without canals.	
From—	To—													Acre-feet per day.	Cubic feet per second.	Acre-feet per day.	Cubic feet per second.
1906.	1906.																
Jan. 1	Jan. 10	38	26	1.4	15	4.4	24	0.3	0.0	81	10	14	100	248	125	171	86.2
Jan. 11	Jan. 20	184	20	3.4	5.7	3.9	13	1.5	.0	41	14	5.9	...	13,456	6,784	13,135	6,622
Jan. 21	Jan. 30	72	18	2.2	11	4.4	19	2.2	.0	43	14	6.0	52	3,673	1,852	3,233	1,630
Jan. 31	Feb. 9	14	14	2.2	5.4	2.9	....	1.3	.0	38	19	5.4	72	2,298	1,159	1,180	595
Feb. 10	Feb. 19	40	15	1.8	9.1	4.7	8.4	1.2	.0	41	7.6	19	82	3,649	1,845	2,885	1,455
Feb. 20	Mar. 1	100	15	2.8	10	5.3	7.9	2.1	.0	51	9.8	6.1	100	6,875	3,466	6,292	3,172
Mar. 2	Mar. 11	64	15	2.6	9.4	5.1	8.0	1.5	.0	47	13	6.7	76	5,543	2,795	5,345	2,695
Mar. 12	Mar. 21	198	12	4.0	9.4	5.6	4.1	1.3	.0	46	9.2	5.9	70	15,547	7,838	15,257	7,692
Apr. 1	Apr. 10	82	16	4.8	11	5.1	14	3.8	.0	36	16	5.9	76	11,572	5,834	11,312	5,703
Apr. 11	Apr. 20	70	8.6	2.4	6.3	5.4	8.8	1.3	.0	26	4.8	3.9	48	12,522	6,313	11,608	5,852
Apr. 21	Apr. 30	84	7.2	3.0	7.7	4.6	5.8	1.2	.0	27	7.9	4.9	56	14,611	7,366	13,442	6,777
May 1	May 9	88	8.6	2.4	6.6	1.9	3.8	1.4	.0	25	4.8	4.5	58	19,776	9,970	18,054	9,102
May 11	May 20	68	10	2.8	5.1	1.7	6.9	1.9	.0	19	4.4	4.9	62	23,516	11,856	20,672	10,422
May 21	May 30	102	11	2.4	6.5	3.0	7.7	1.3	.0	20	9.2	4.1	42	22,215	11,200	20,896	10,535
May 31	June 10	24	7.6	4.0	9.7	3.9	6.6	2.6	.0	21	21	4.7	60	20,533	10,352	18,995	9,576
June 11	June 20	38	6.6	3.4	5.7	3.2	6.9	0.6	.0	16	6.9	3.9	42	33,525	16,902	31,618	15,941
June 21	June 30	20	6	3.0	3.7	2.0	8.5	0.8	.0	15	7.7	4.9	40	28,727	14,483	26,727	13,475

[a] For data concerning gage heights and discharges see Water-Supply Papers U. S. Geol. Survey Nos. 81, 85, 100, 134, 177, and 213.

Mineral analyses of water from Tuolumne River at Lagrange—Continued.

Date.		Suspended matter.	Silica (SiO_2).	Fe.	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Total solids.	Mean discharge, including canals.		Mean discharge, without canals.	
From—	To—												Acre-feet per day.	Cubic feet per second.	Acre-feet per day.	Cubic feet per second.
1906.	1906.															
July 1	July 10	28	5.4	.10	5.1	4.0	5.4	.0	13	6.3	3.9	42	31,893	16,079	29,891	15,070
July 11	July 20	26	8.4	.05	5.1	1.9	7.9	.0	17	7.1	4.7	54	22,795	11,493	20,829	10,501
July 21	July 31	44	5.2	.10	4.9	1.4	9.0	.0	15	3.8	4.9	42	15,346	7,737	13,372	6,742
Aug. 1	Aug. 10	16	11	.07	7.9	2.1	11	.0	21	11	4.8	42	6,635	3,345	4,689	2,364
Aug. 11	Aug. 20	68	4.8	.18	7.4	3.0	8.0	4.0	14	5.8	5.8	46	4,300	2,168	3,040	1,533
Aug. 22	Aug. 29	88	6.6	.23	11	3.6	6.3	.0	30	7.9	4.9	46	2,560	1,291	1,418	715
Sept. 1	Sept. 9	74	6.6	.18	8.0	5.0	17	.0	52	8.1	10	74	132	66.4	48.4	24.4
Sept. 11	Sept. 20	18	9.8	.20	7.2	4.7	18	.0	52	9.1	8.1	82	86.7	43.7	0	0
Sept. 21	Sept. 30	20	16	.10	12	5.4	24	.0	59	15	8.1	112	629	317	0	0
Oct. 1	Oct. 10	46	8.8	.10	16	5.4	12	.0	73	13	6.1	92	550	277	69.4	35.0
Oct. 11	Oct. 20	50	11	.20	16	7.5	13	.0	65	18	7.6	104	457	230	181	91.5
Oct. 21	Oct. 31	50	11	.10	18	6.4	13	.0	72	17	7.1	134	289	146	289	146
Nov. 1	Nov. 9	96	14	.7	21	6.7	19	.0	77	15	8.1	116	536	270	536	270
Nov. 11	Nov. 20	12	8.8	.25	12	5.1	14	.0	53	28	7.6	100	577	291	577	291
Nov. 22	Nov. 30	32	9.8	.10	17	5.1	15	.0	64	10	7.1	88	321	162	321	162
Dec. 1	Dec. 10	72	16	.10	18	5.3	12	.0	65	15	7.1	122	457	230	457	230
Dec. 11	Dec. 20	284	8.4	.5	17	6.8	14	.0	72	21	7.1	94	3,456	1,743	3,456	1,743
Dec. 21	Dec. 31	64	7.4	.20	10	4.8	13	.0	39	13	5.6	74	4,647	2,343	4,647	2,343
Mean		68	11	[a].19	10	4.3	12	.0	41	12	6.6	74	9,542	4,811	.....	.....
Per cent of anhydrous residue		....	14.4	0.2	13.1	5.6	15.8	26.3	....	15.8	8.8	...	.....	.....	.....	.....

[a] Mean of Fe values after July 1.

MERCED RIVER.

DESCRIPTION.

Merced River drains that portion of the western slope of the Sierra Nevada located between Tuolumne River on the north and the San Joaquin on the south, its drainage area being much smaller than that of the Tuolumne. It has numerous tributaries, many of which are of considerable size. The general course of the stream is from the mountains westward to southwestward, and it enters San Joaquin River near Newman.

The topography of this drainage area resembles that of Tuolumne River, being rough and broken in the upper reaches. This basin includes the Yosemite National Park and Yosemite Valley, with its precipitous walls and domes, and the great waterfalls, which plunge into the valley over cliffs that rise 2,000 to 3,000 feet above its floor.

On the upper reaches of the basin above Yosemite Valley the bed rock is granite, worn bare and smooth by glacial action. The middle reaches of the basin are well timbered. In the basin of the South Fork is the Mariposa grove of big trees. The timber growth extends well down into the lower elevations of the foothills, where the covering is brush and grass, which is used extensively for pasturage. Numerous lakes are scattered over the upper portion of the basin. The precipitation in the upper areas is largely in the form of snow, which melts in the spring except on some of the highest peaks, where it may remain during the entire year. Below Merced Falls canals divert

water for the irrigation of lands along the river bottoms and in the San Joaquin Valley.

CHARACTER OF WATER AT MERCED FALLS.

Samples for this investiagtion were collected at the gaging station at Merced Falls[a] by the gage reader. The stream at this point runs in a rocky bed walled in on both sides by high, steep banks. The bed is of gravel and is subject to some change at high water. Owing to the similarity between the results obtained during the first six months on this stream and on the Stanislaus and Tuolumne, which drain practically the same watersheds, work was discontinued at the end of July on Merced and Stanislaus rivers and only the Tuolumne station was kept up. The results of the investigation are presented in the accompanying analyses.

The total mineral matter is low, as would be expected from a stream draining an area whose rocks are almost entirely granite. Except for the small amount of suspended matter, the water is fit for almost any industrial use, and, if filtered, it would constitute an excellent domestic supply. The water is now being used only for irrigation.

Mineral analyses of water from Merced River at Merced Falls.

[Parts per million unless otherwise stated.]

Date.		Suspended matter.	Silica (SiO_2).	$Fe_2O_3+Al_2O_3$.	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Total solids.	Mean discharge.	
From—	To—													Acre-feet per day.	Cubic feet per second.
1906.	1906.														
Jan. 1	Jan. 10	36	24	1.2	21	5.6	15	.03	0.0	77	19	9.4	116	206	104
Jan. 11	Jan. 20	260	27	1.4	8.3	4.0	11	2.9	.0	41	13	4.4	68	9,211	4,644
Jan. 21	Jan. 30	.....	17	1.6	9.1	4.6	16	2.0	.0	40	42	4.9	.....	1,837	926
Jan. 31	Feb. 9	8	18	3.0	9.4	3.9	6.9	1.9	.0	43	15	5.9	68	928	468
Feb. 10	Feb. 19	18	20	1.2	7.4	3.1	7.2	1.3	.0	43	11	8.3	86	1,475	744
Feb. 20	Mar. 1	30	18	3.2	13	5.1	6.5	1.4	.0	51	7.9	6.9	86	3,897	1,965
Mar. 2	Mar. 11	6.0	13	1.2	15	5.3	5.5	.5	.0	49	11	8.0	88	3,290	1,659
Mar. 12	Mar. 21	86	15	4.6	7.7	4.8	8.0	1.3	.0	62	7.6	6.9	82	11,584	5,840
Apr. 1	Apr. 10	66	13	3.0	10	4.9	7.7	2.1	.0	47	10	5.5	74	6,794	3,425
Apr. 11	Apr. 20	66	12	2.6	9.7	5.0	6.6	2.5	.0	31	12	4.9	68	6,024	3,037
Apr. 21	Apr. 27	100	16	3.0	8.3	6.3	5.5	1.3	.0	28	5.4	3.9	42	8,136	4,102
May 2	May 10	40	9.4	2.8	10	2.4	4.9	1.7	.0	30	7.4	4.9	54	11,465	5,780
May 11	May 20	8.0	10	2.0	7.7	2.6	8.0	2.0	.0	20	4.3	4.9	68	13,350	6,731
May 21	May 30	.....	6.8	2.6	5.7	3.1	4.7	1.3	.0	21	9.2	5.9	40	14,785	7,454
May 31	June 10	16	15	3.4	9.1	2.0	7.9	.....	.0	25	8.6	4.9	62	11,858	5,978
June 11	June 20	32	6.4	3.6	4.8	3.9	6.8	.6	.0	16	8.6	3.4	54	20,262	10,215
June 21	June 30	68	6.4	4.6	6.9	1.7	8.2		.0	17	7.6	4.9	50	18,913	9,535
July 1	July 10	32	15	1.0	8.0	4.2	13		.0	17	7.3	3.9	40	18,718	9,437
				Fe.											
July 11	July 20	24	6.2	.10	4.0	1.5	6.5		.0	17	5.6	4.7	46	12,665	6,385
July 21	July 31	38	16	.10	6.9	1.3	6.3		.0	18	3.3	4.5	48	6,467	3,260
Mean		52	14	[b].10	9.1	3.8	9.3		.0	35	11	5.6	65	9,095	4,584
Per cent of anhydrous residue		.....	20	0.2	13.0	5.4	13.3		24.3	.....	15.8	8.0	.....	.....	.....

[a] For data regarding gage heights and stream flow see Water-Supply Papers U. S. Geol. Survey Nos. 134, 177, and 213.

[b] Mean of Fe values after July 1.

KERN RIVER.

DESCRIPTION.

Kern River, rising in the highest elevations of the Sierra Nevada at the extreme southern limit of the range, and collecting its waters from the western and southern slopes of Mount Whitney and numerous other high peaks grouped around it which reach altitudes exceeding 14,000 feet above sea level, discharges into the San Joaquin just east of Bakersfield. For about 65 miles its course is in general southward; it then turns and flows southwestward into the valley. Its drainage basin, 2,345 square miles in extent, is larger than that of any other tributary of the San Joaquin. The Kern receives numerous tributaries, the principal ones draining the higher elevations of the main crest of the Sierra and entering from the east.

The topography of the basin is extremely rough and broken in the upper reaches, becoming less rugged in the middle areas in the vicinity of Kernville, where there is a large, cultivated valley. Below this valley the stream enters a rough canyon, from which it emerges into the flat country of the San Joaquin Valley. The entire flow of the stream, except during extreme flood stages, is diverted and used for irrigation at points where the river emerges from the foothills.

The bed rock of the Kern basin is largely granite. Above an altitude of 10,000 feet vegetation is practically absent, but between altitudes of 3,000 and 10,000 feet there is good depth of soil, with timber and brush covering. The lower reaches have a light covering of brush and grass.

A number of lakes and marshes are scattered throughout this basin, but they are less numerous than in the basins farther north. Several power plants are located on the Kern, none of which, however, receive water from storage reservoirs, the diversions being made from the natural flow of the stream and again returned to the river channel.

The precipitation is very light throughout the basin except on the higher elevations, where snow remains through the summer months. For this reason there are few floods during the winter and in the early spring, the periods of highest water occurring some time during the summer.

CHARACTER OF WATER NEAR BAKERSFIELD.

Samples of water for this investigation were collected at the gaging station of the Kern County Land Company about 5 miles above Bakersfield and at the mouth of the canyon.[a] The stream at this place is wide and shallow at ordinary stages, with sandy bottom. The channel has been improved as much as possible above and below

[a] For data concerning gage heights and discharge, see Water-Supply Papers U. S. Geol. Survey Nos. 85, 100, 134, 177, and 213.

the gaging station to facilitate measurement. The results of the investigation are presented in the accompanying analyses.

The dissolved solids are not high, and the water is well adapted for industrial use if clarified, for it contains little else except calcium, magnesium, and bicarbonates in solution.

During the greater part of the year it would probably be necessary to add small quantities of soda ash or some such scale preventive if the water were used in boilers, but the deposit formed would not be of objectionable character and could be readily removed. The amount of suspended matter carried by the river in times of flood is never very great, and owing to its coarse, sandy character it readily settles out on standing.

Mineral analyses of water from Kern River at Bakersfield.

[Parts per million unless otherwise stated.]

Date.		Suspended matter.	Silica (SiO_2).	$Fe_2O_3+Al_2O_3$.	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Total solids.	Mean discharge.	
From—	To—													Acre-feet per day.	Cubic feet per second.
1906.	1906.														
Jan. 1	Jan. 10	14	44	2.2	23	5.3	40	0.4	0.0	107	24	13	170	492	248
Jan. 11	Jan. 19	32	29	.8	23	5.4	25	2.1	.0	92	41	12	210	1,874	945
Jan. 21	Jan. 30	50	24	2.4	19	3.2	24	2.4	.0	89	25	13	158	1,467	740
Jan. 31	Feb. 9	1,836	22	.8	39	6.1	105	2.6	.0	110	71	14	270	1,083	546
Feb. 10	Feb. 19	Trace.	26	1.6	26	3.9	19	1.3	.0	96	37	15	200	1,220	615
Feb. 20	Mar. 1	1,168	22	1.8	22	3.3	59	2.2	.0	97	24	12	162	2,669	1,346
Mar. 2	Mar. 11	144	18	3.4	21	5.4	25	2.9	.0	90	33	14	134	1,597	805
Mar. 12	Mar. 21	196	25	5.4	19	3.8	14	3.8	.0	71	18	12	152	5,185	2,614
Mar. 23	Mar. 31	166	23	6.0	17	4.6	12	2.8	.0	74	16	17	142	5,963	3,006
Apr. 1	Apr. 9	88	23	5.2	16	4.0	16	3.1	.0	69	18	7.6	128	4,258	2,298
Apr. 11	Apr. 20	398	21	4.6	21	9.4	15	2.7	.0	90	22	9.8	190	5,405	2,725
Apr. 21	Apr. 30	102	11	.....	19	8.9	13	1.8	.0	54	15	6.9	88	7,351	3,706
May 2	May 9	112	19	3.2	18	5.3	9.8	1.2	.0	53	11	6.9	112	8,263	4,166
May 11	May 20	170	18	3.2	9.4	3.2	11	.6	.0	46	6.8	6.4	84	12,429	6,266
May 21	May 31	146	12	4.2	13	4.3	10	1.3	.0	40	14	5.4	94	13,706	6,910
June 1	June 10	60	16	3.6	12	3.6	9.3	1.0	.0	43	16	6.9	82	11,602	5,849
June 12	June 20	130	11	4.6	8.3	3.5	10	.9	.0	33	9.1	4.5	70	17,742	8,945
June 21	June 30	128	12	5.0	10	2.6	12		.0	30	9.4	4.4	56	32,811	16,542
				Fe.											
July 1	July 10	116	12	.23	7.4	2.8	16		.0	36	12	4.6	68	15,623	7,876
July 11	July 20	126	7.4	.10	4.9	1.4	9.5		.0	32	10	5.3	60	28,779	14,509
July 21	July 31	90	9.4	.10	8.6	1.6	9		.0	30	5.8	5.8	56	10,189	5,137
Aug. 1	Aug. 10	30	12	.10	15	2.5	12		.0	38	13	5.8	78	5,991	3,020
Aug. 11	Aug. 19	30	12	.13	9.4	3.1	14		.0	44	10	5.3	80	4,616	2,327
Aug. 23	Aug. 30	22	20	.18	13	3.3	18		.0	57	14	6.4	118	3,011	1,518
Sept. 1	Sept. 10	28	11	.13	17	3.8	19		.0	60	18	6.8	102	2,471	1,246
Sept. 11	Sept. 20	18	23	.25	16	3.5	13		.0	63	17	7.6	114	1,803	909
Spet. 21	Sept. 30	30	15	.10	18	3.9	26		.0	72	16	8.1	118	1,517	765
Oct. 1	Oct. 10	30	14	.10	15	3.0	20		.0	80	18	7.1	114	1,319	665
Oct. 11	Oct. 20	Trace.	15	.10	25	5.5	23		.0	89	23	9.1	148	1,202	606
Oct. 21	Oct. 31	26	14	.10	22	3.5	22		.0	97	27	10	146	1,113	561
Nov. 1	Nov. 10	Trace.	14	.50	21	4.2	22		.0	95	26	10	146	1,091	550
Nov. 11	Nov. 17	18	20	.10	24	5.0	26		.0	100	30	11	148	1,004	506
Nov. 22	Nov. 30	14	17	.15	26	5.5	25		.0	105	27	10	150	930	469
Dec. 1	Dec. 10	22	16	.10	22	4.3	26		.0	89	26	14	162	1,101	555
Dec. 11	Dec. 12	.....	.....	.....	.....	.....	.....		.0	107	.....	10	.....	1,319	665
Mean		163	18	a.15	18	4.2	22		.0	71	21	9.1	127	6,234	3,147
Per cent of anhydrous residue		.....	14.1	0.1	14.1	3.3	17.3		27.5	.....	16.5	7.1	.....	.....	.....

a Mean of Fe values after July 1.

TULARE LAKE.

Tulare Lake is a shallow body of water lying in a large, elongated depression just south of Kings River. Its level fluctuates widely from year to year; at times it is of great extent; at other times its bed is practically dry. Its drainage area also is indefinite: Sometimes the waters of Kings River overflow into it; sometimes it discharges into Kings River; and sometimes there is no flow in either direction. In 1906 the bed was dry and large grainfields covered the lake floor; in 1909 the water area was many miles in extent.

The reason for these peculiar fluctuations in size and drainage is to be found in the climate and topography of the region. The alluvial divide between Tulare Lake and San Joaquin River is low; the bottom of Tulare Lake is at a level not differing greatly from that of the bottom of Kings River; hence the relative levels of the water in the two must determine the direction of flow. Floods in Kings River will send discharge waters into Tulare Lake, and low water in Kings River will cause flow in the opposite direction. The connection between the two, however, is not constant, and in times of low water it is absent altogether. At such times Tulare Lake gradually dries up and becomes a gently sloping valley.

In 1889 this process of evaporation had been in progress for several years and the waters of the lake were so concentrated as to be unfit for irrigation or other purposes. At this time an analysis of the water was made for Prof. E. W. Hilgard, of the University of California, and this analysis is here given to show the interesting results of concentration on the waters of the region.

Analysis of water of Tulare Lake, February, 1889.[a]

[Parts per million.]

Silica (SiO_2)	32	Carbonate radicle (CO_3)	958
Calcium (Ca)	13	Sulphate radicle (SO_4)	1,023
Magnesium (Mg)	11	Chlorine (Cl)	996
Sodium (Na)	1,763	Organic matter	227
Potassium (K)	121	Total solids	5,195

The analysis shows a strong alkaline sulphated water, with smaller amounts of the chlorides and carbonates.

ALAMEDA CREEK.

DESCRIPTION.

Alameda Creek drains that part of the Coast Range immediately east and south of San Francisco Bay. The creek rises in the Mount Diablo Range in the vicinity of Mount Hamilton, flows north and northwestward for about 30 miles, and empties into San Francisco Bay in the vicinity of Alvarado. The basin, steep and rough in its

[a] Hilgard, E. W., in appendix to Rept. Univ. California, Exper. Sta., 1890.

upper reaches, broadens out in the lower into pleasant valleys and sloping hillsides, which are extensively cultivated. Precipitation in this basin is almost wholly in the form of rain; any snow that may fall during the winter season soon melts and goes to swell the floods of early spring.

CHARACTER OF WATER AT NILES.

Samples of water for this investigation were collected at a point on the stream just above the stone dam above Niles by Fred Scott, the study of the creek waters having been included in this work at the request of Prof. Andrew C. Lawson, of the University of California. The bed of the creek at the sampling point is intercepted by rock strata, which serve to bring most of the underground flow to the surface. The results of the study are indicated in the accompanying analyses.

Mineral analyses of water from Alameda Creek at Niles.

[Parts per million unless otherwise stated.]

Date.		Suspended matter.	Silica (SiO_2).	$Fe_2O_3+Al_2O_3$.	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Total solids.
From—	To—												
1906.	1906.												
Jan. 1	Jan. 10	20	23	2.0	102	40	72	2.2	0.0	356	170	36	600
Jan. 11	Jan. 19	1,482	18	.6	35	12	10	2.3	.0	119	42	18	234
Jan. 21	Jan. 30	36	21	2.0	51	19	28	3.8	.0	188	56	26	332
Jan. 31	Feb. 9	Trace.	20	2.0	64	26	38	2.7	.0	243	86	38	400
Feb. 10	Feb. 19	90	21	1.8	71	25	44	2.8	.0	247	80	43	406
Feb. 20	Mar. 1	314	17	3.4	31	13	21	3.0	.0	142	30	27	228
Mar. 2	Mar. 11	110	14	3.2	37	16	22	1.3	.0	168	38	20	250
Mar. 12	Mar. 21	826	12	2.6	32	14	17	3.1	.0	139	32	24	216
Mar. 22	Mar. 31	1,112	15	2.4	39	14	22	4.8	.0	151	29	23	240
Apr. 1	Apr. 10	42	21	3.0	39	17	23	2.3	.0	182	36	22	322
Apr. 11	Apr. 20	76	18	4.4	77	25	36	4.6	.0	232	67	29	324
Apr. 21	Apr. 22	.....	.....	.....	.....	.....	.....	.....	.....	240	.....	29	.....
May 2	May 10	26	17	3.8	57	24	36	1.9	.0	255	58	33	374
May 11	May 20	26	18	3.0	62	24	41	1.6	3.3	256	60	35	362
May 21	May 30	26	17	3.8	57	25	32	3.4	3.8	251	63	39	382
May 31	June 10	.....	20	4.2	56	25	37	2.5	10	242	62	39	404
June 11	June 20	.....	17	4.8	58	27	50	2.7	.0	270	63	36	398
June 21	June 30	26	21	2.4	62	32	56	5.0	5.1	273	68	41	420
				Fe.									
July 1	July 10	46	19	.06	58	30	66		14	257	80	42	412
July 11	July 18	36	20	.05	57	29	48		10	268	68	40	428
July 21	July 31	160	20	.05	64	32	56		.0	296	100	37	466
Aug. 1	Aug. 10	Trace.	21	.05	96	30	55		8.0	264	82	36	422
Aug. 11	Aug. 20	12	25	.20	62	30	50		.0	287	113	33	410
Aug. 21	Aug. 30	14	20	.10	79	34	82		7.0	286	126	36	480
Sept. 1	Sept. 10	Trace.	20	.13	90	36	55		10	290	122	35	510
Sept. 11	Sept. 20	6	23	.10	70	34	73		12	249	124	38	502
Sept. 21	Sept. 30	Trace.	17	.05	87	34	61		10	327	123	41	504
Oct. 1	Oct. 10	8	16	.10	92	40	65		9.0	339	149	39	562
Oct. 11	Oct. 20	38	19	.15	90	40	50		10	329	152	40	584
Oct. 21	Oct. 30	.....	17	.40	89	42	70		16	342	174	42	610
Nov. 8	Nov. 10	.....	.....	.....	.....	.....	.....		.0	358	.....	35	.....
Nov. 11	Nov. 20	10	19	.20	94	44	72		10	396	202	42	654
Nov. 21	Nov. 30	24	23	.15	98	42	71		4.0	420	160	37	606
Mean.....		163	19	[a].13	66	28	49		4.4	262	91	34	421
Per cent of anhydrous residue..		.....	4.5	0.0	15.7	6.6	11.7		31.8	.....	21.6	8.1	.....

[a] Mean of Fe values after July 1.

At flood times the stream carries an excessive amount of suspended matter, both coarse sand picked up from the bed of the creek and finer material washed down from the adobe-like soil of the hillsides. As the waters subside they gradually become clearer, until at low stages they are quite clear. The mineral matter in solution is of considerable interest, containing as it does such a high proportion of magnesium. This is dissolved from the shales and magnesian limestones which are said to occur in considerable amounts in the vicinity of Livermore. This magnesium renders the water troublesome when used in boilers, and some form of softener or scale preventive is needed.

The waters of Alameda Creek are especially important because of the fact that a portion of the present water supply of San Francisco is drawn from wells sunk in the gravel beds of some of the tributary streams in the vicinity of Sunol. Furthermore, the waters of the creek, after leaving the hills near Niles, sink into deep gravel beds extending from the mouth of the canyon to the bay, and a number of driven wells in the lower end of these gravel beds furnish a part of the public supply for the city of Oakland. The reservoir furnishing the main supply for Oakland is located in the next drainage area north of Alameda Creek. The quality of these public supplies is well guarded. The first, that of San Francisco, is protected from contamination by patrolling the catchment basin; the second, the wells driven into the gravels, is probably free from pollution because of the efficient filtering action of the thick layers of gravel and sand; and the third, the impounded surface waters in the basin north of Alameda Creek, are protected by thorough inspection and are purified by filtration.

NOTES ON MUNICIPALITIES.

Reports were received from 79 settlements in the San Francisco Bay drainage area, including 24 cities and towns in the Sacramento Valley, 18 in the San Joaquin Valley, and 37 in the region bordering the bay.

In the Sacramento Valley 10 towns and cities report the use of surface water only, while one town reports a combination of stream and well water. The per capita consumption is generally high and includes large quantities of irrigation waters.

In the San Joaquin Valley 5 towns reported use of surface waters, one reported water obtained by railroad transportation, and the rest reported underground supplies. Data as to consumption were generally lacking.

Of the bay cities 15 places reported the use of surface water only, 9 reported using both surface and ground water, and 13 places used wells. The tabulated statistics follow.

Statistics of municipal water supplies in San Francisco Bay drainage basin.

SACRAMENTO RIVER.

Settlement.	Drainage basin.	Population.	Adjacent to—	Source of supply.	Nature of system.	Ownership.	Methods used for purification.	Daily consumption per capita (gallons).	Nature of sewerage system.	Ultimate disposal of sewage.
Alturas	Pit River	[a] 1,250	Pit River	Wells	Pumping	Individual	None		No system	
Auburn	American River	2,460	American River	South Yuba River	Gravity	South Yuba Water Co.	do		Sanitary—septic tank.	Auburn Ravine.
Biggs		[a] 875	Doe Creek	Wells	Pumping	Municipal	do		No system	
Chico	Sacramento River.	[b] 3,888	Sacramento River.	Shallow wells	do	Chico Water Supply Co.	do		Combined	Sewer farm.
Colusa	do	1,535	do	Stream and wells	do	Mrs. J. B. Cooke	do		No system	
Corning	do	[a] 1,200		Wells	do	A. Watkinson	do		do	
Dixon	do	783		do	do	Dixon Electric Power and Water Co.	do	60	None	
Grass Valley	Bear River	4,869	Bear River	South Yuba River	Gravity	South Yuba Water Co.	do	250 to 300	Sanitary	
Gridley	Feather River	[a] 1,700	Feather River	Wells	Pumping	Municipal	do		No system	
Lincoln	Sacramento River.	762	Auburn Ravine	Streams	Gravity	do	do		Sanitary	Do.
Marysville	Feather River	3,500	Feather River	Wells	Pumping	do	do	96	Combined	Deer Creek.
Nevada City	Yuba River	3,903	Yuba River	South Yuba River	Gravity	South Yuba Water Co.	do	300	No system	
Oroville	Feather River	3,500	Feather River	Feather River	do	Oroville Water, Light and Power Co.	do	[c] 6,000	Storm	Creek.
Placerville	American River	1,800	American River	Lakes and stream	do	Municipal	do	480	Separate systems	Sacramento River.
Red Bluff	Sacramento River.	2,878	Sacramento River.	Antelope Creek and Sacramento River.	Gravity and pumping.	Red Bluff Water Co.	do	240 to 400	Combined	Do.
Redding	do	3,500	do	Wells	do	Redding Water Co	do	150 to 260	No system	
Rocklin	do	1,050	Antelope Creek	Stream	Gravity	South Yuba Water Co.	do		Sanitary	Do.
Sacramento	do	31,892	Sacramento River.	Sacramento River	Pumping	Municipal	do	275	No system	
Sisson	do	[a] 700	do	Stream	Gravity	Sisson Development Co.	do		do	
Tehama		[a] 500		Sacramento River	Pumping	John Simpson	do		None	
Willows	Sacramento River.	893	Willow Creek	Wells	do	Northern California Power Co.	do		Storm only	Puta Creek.

Winters	do	a 1,100	Puta Creek	do	do	Municipal	do	200	Sanitary	Tule swamp.
Woodland	do	2,886	Sacramento River.	do	do	do	do			
Yuba City	do	a 1,200		do	do	do	do		Storm only	Slough.

a Estimates of local authorities; census figures lacking.
b Census of 1906. California Blue Book, 1907. All others estimated for 1909 from United States Census reports of 1890 and 1900.
c Including irrigation water.

SAN JOAQUIN RIVER.

Angels Camp	Stanislaus River.	a 3,000	Stanislaus River.	Stanislaus River	Gravity	Utica Mining Co.	None		No system	
Bakersfield	Kern River	6,876	Kern River	Shallow wells	Pumping	Electric Water Co.	do	250 to 600	Separate system	Sewer farm.
Coalinga	San Joaquin River.	a 3,500	Arroyo Los Gatos.	Brought in by rail.		Pleasant Valley Water Co.	do		No system	
Fresno	do	13,955	San Joaquin River.	Deep wells	Pumping	Fresno City Water Co.	do		Sanitary—septic tank.	Do.
Jackson	Mokelumne River.	3,000	Jackson Creek	Stream	Gravity	Pacific Gas and Electric Co.	do		No system	
Kern City	Kern River	a 3,300	Kern River	Wells	Pumping	Kern Sewerage Co.	do	500	Combined	Open desert.
Lodi	Mokelumne River.	a 3,500	Mokelumne River.	do	do	Cary Bros.	do		No system	
Los Banos	San Joaquin River.	1,000	Los Banos Creek.	Canal	do	Miller & Lux	do		do	
Madera	Fresno River		Fresno River	Wells	do	Municipal	do	60	Storm	
Merced	San Joaquin River.	2,000		Merced River	Gravity		do		Sanitary	Sewer farm.
Modesto	Tuolumne River.	a 4,000	Tuolumne River.	Wells	Pumping		do	250	do	
Oakdale	Stanislaus River.	1,203	Stanislaus River.	do	do	Municipal	do	75	No system	
Porterville	Tulare River	a 2,000	Tulare River	do	do	do	do		do	
Selma	Kings River	1,083	Kings River	do	do	San Joaquin Light and Power Co.	do		do	
Sonora	Stanislaus River.	2,354	Stanislaus River.	Streams	Gravity and pumping.	Gold Mountain Water Co.	do	60	Sanitary	Creek ¼ mile below town.
Stockton	San Joaquin River.	20,280	San Joaquin River.	Artesian wells	Pumping	Stockton Water Co	do	128	Combined	San Joaquin River.
Tulare	Kaweah River	2,216	Tule River	Wells	do	Municipal	do		No system	
Visalia	do	3,265	Kaweah River	do	do		do	100	Sanitary	Sewer farm.

a Based on estimates of town or city clerks and health officers. All others estimated for 1909 from United States Census reports of 1890 and 1900.

Statistics of municipal water supplies in San Francisco Bay drainage basin—Continued.

BAY REGION.

Settlement.	Drainage basin.	Population.	Adjacent to—	Source of supply.	Nature of system.	Ownership.	Methods used for purification.	Daily consumption per capita (gallons).	Nature of sewerage system.	Ultimate disposal of sewage.
Alameda	San Francisco Bay.		San Francisco Bay.	Wells	Pumping	Peoples Water Co.	None	50		
Alviso	do	a 200	Coyote River	do	do	W. A. Wood	do		No system	
Antioch	do	a 2,000	Suisun Bay	Stream	do	Municipal	do	100	Sanitary	San Francisco Bay.
Belvedere	do	a 650	San Francisco Bay.	Stream and wells	Gravity	Belvedere Land Co.	do		do	Do.
Benicia	do	3,102	Straits of Carquinez	Lake Herman	Gravity and pumping.	Benicia Water Co.	do	200	Combined	Carquinez Straits.
Berkeley	do	a 26,283	San Francisco Bay.	Streams and wells	do	Peoples Water Co.	Filtration of surface supply.	50	do	San Francisco Bay.
Black Diamond	do		Suisun Bay	San Joaquin River	Pumping	Black Diamond Water Co.	None	150	Sanitary	San Joaquin River.
Calistoga	do	a 1,000	Napa Creek	Streams	Gravity	Calistoga Water Co.	do		No system	
Emeryville	do	1,725	San Francisco Bay.	Streams and wells	Gravity and pumping.	Peoples Water Co.	Filtration of surface supply.	95		
Fairfield	do	a 1,100	Suisun Bay	Wells	Pumping	Henry Goosen	None	250	Sanitary	Suisun Bay.
Hayward	do	2,456	San Lorenzo Creek.	Artesian wells	do	Municipal	do	100	do	San Francisco Bay.
Livermore	do	1,584	Mocho Creek	Mocho Creek and wells.	Gravity and pumping.	Livermore Water and Power Co.	do	150	No system	
Los Gatos	do	2,152	Los Gatos Creek	Stream	Gravity	San Jose Water Co.	do		Sanitary—septic tank.	Los Gatos Creek.
Martinez	do	a 1,500	Suisun Bay	Artesian wells	Pumping	Port Costa Water Co.	do	60		San Francisco Bay.
Mill Valley	do	a 3,500	Mill Creek	Streams	Gravity	North Coast Water Co.	do		Sanitary	Do.
Morgan Hill	do	a 600		do	do	Private companies	do		No system	
Mountain View	do	a 1,500	Stevens Creek	Artesian wells	Pumping	Municipal	do	24	do	
Napa	do	4,036	Napa Creek	Stream and wells	do	Napa City Water Co.	Lime and iron coagulation.	120	Separate systems	

Oakland	do	238,010	San Francisco Bay.	Streams and wells.	Gravity and pumping.	Peoples Water Co.	Filtration of surface supply.	95	Combined	Do.
Palo Alto	do	3,500	San Francisquito Creek.	Wells	Pumping		None	100	Sanitary	Do.
Petaluma	do	4,035	Petaluma Creek	Streams	Gravity		do	125	do	Petaluma River.
Piedmont	do	a 1,900		Streams and tunnels.	Gravity and pumping.	Peoples Water Co.	Filtration of surface supply.	75	Combined	San Francisco Bay.
Pleasanton	do	a 1,800	Arroyo Valley	Wells	Pumping	Municipal	None	65	No system	
Redwood	do	1,725	Redwood Creek	Artesian wells	do	do	do	42	Sanitary	Redwood Creek.
Richmond	do	a 9,000	San Francisco Bay.	Wells	do	Peoples Water Co.	do	152	Separate systems	San Francisco Bay.
Rio Vista	do	713	Sacramento River.	Stream	do	Municipal	Filter tanks.	70	No system	
San Anselmo	do	a 1,800	Corte Madera Creek.	Lakes	Gravity and pumping.	Marin Water and Power Co.	None	350	Sanitary	Do.
San Francisco	do	450,000	San Francisco Bay.	Streams, artesian wells, and filter galleries.	do	Spring Valley Water Co.	Part of supply filtered.	85	Separate systems	Pacific Ocean.
San Jose	do	24,596	Coyote River	Stream and wells	do	San Jose Water Co.	None	175	Sanitary	San Francisco Bay.
San Leandro	do	a 2,500	San Leandro Creek.	Streams	Gravity	Peoples Water Co.	Filtration.	140	do	Do.
San Mateo	do	a 3,500	San Mateo Creek.	Wells	Pumping	San Mateo Water Co.	Filtered.	30 to 40	do	Do.
San Rafael	do	4,410	San Rafael Creek.	Streams	Gravity and pumping.	Marin County Water Co.	None	350	do	Salt water creek.
Santa Clara	do	4,423	San Tomas Aguinas Creek.	Artesian wells	Pumping	Municipal	do	102	do	Septic tank under construction.
Sausalito	do	1,893	San Francisco Bay.	Streams					Combined	San Francisco Bay.
Saint Helena	do	1,582	Napa Creek	York Creek	Gravity	Saint Helena Water Co.	None	150 to 200	Sanitary	Sewer farm.
Suisun	do	738	Suisun Creek	Streams	do	Municipal	do		do	Suisun Bay.
Vacaville	do	1,665	Alamo Creek	Wells	Pumping		do	100	Sanitary—septic tank.	

a Based on estimates of town or city clerks and health officers. All others estimated for 1909 from United States Census reports of 1890 and 1900.

SOUTH PACIFIC OCEAN DRAINAGE.

DESCRIPTION.

The south Pacific Ocean drainage area includes the narrow strip of land extending from San Francisco Bay to the Mexican boundary, a distance of about 350 miles, and bordered on the east by the Coast Ranges, the San Bernardino Mountains, and the San Jacinto Mountains. Its area of 23,000 square miles includes the fertile Salinas Valley, the great orange belt of southern California, and the San Diego lands. (See Pl. I, in pocket.)

Important among the river systems lying within this area are the Salinas, the Santa Maria, the Santa Ana, and the San Gabriel. The area includes also many smaller river systems, which, owing to the generally deficient rainfall of the region, are of great local importance. Much attention is being paid to the proper development of the water resources of this strip of coastal land, and for this reason special stress was laid upon investigations of the rivers utilized for irrigation. Systematic studies have been made of the waters of the Salinas system and the streams of the valley of southern California, as well as of the other more important rivers of the area. The principal streams in this drainage area are grouped in geographic order (north to south) in the table below:

Principal rivers of south Pacific Ocean drainage.

Monterey Bay subdrainage.
- San Lorenzo River.
- Pajaro River.
  - San Benito River.
  - Pescadero Creek.
- Salinas River.
  - Chalone Creek.
  - San Lorenzo Creek.
  - Gaviota Creek.
  - Indian Valley Creek.
  - Estrella River.
    - San Juan Creek.
    - Cholame Creek.
  - Nacimiento River.
  - San Antonio River.
  - Arroyo Seco.

Carmel River.
Big Sur River.
Little Sur River.
San Luis Obispo Creek.
Santa Maria River.
- Suey Creek.
- Santa Maria River—Continued.
  - Alamos Creek.
  - Sisquoc River.

San Antonio Creek.
Santa Ynez River.
Ventura River.
Santa Clara River.
Malibu Creek.
Valley of southern California.
- Los Angeles River.
- San Gabriel River.
- Rio Hondo.
- Santa Ana River.

Southern subdrainage.
- San Juan Creek.
- Santa Margarita River.
- San Luis Rey River.
- San Dieguito River.
  - Santa Ysabel Creek.
- Otay River.
- Tia Juana.
  - Cottonwood Creek.

The summits of the coast ranges limit the south Pacific Ocean drainage area on the east. Southward from San Francisco Bay these mountains form a more or less broken and ill-defined chain,

being divided into groups or series of parallel ridges following in general the direction of the shore line. The Mount Diablo Range, uniting with the Berkeley and Contra Costa hills on the north, forms with the Santa Cruz and Gabilan Mountains the northernmost group. The Tehachapi Mountains, crisscrossing the southern borders of these, form the connecting link between them and the Sierra Madre and San Bernardino Range of southern California. These in turn give place to the San Jacinto Mountains, which soon lose themselves in the broken and scarcely to be defined ranges of San Diego County.

The underlying formation of the coast ranges is mainly a thick bed composed largely of pre-Cretaceous sandstones and shales. In conjunction with this formation are light, coarse, easily weathered granites and other granitic rocks, which outcrop in various places all along the coastal region. The core of the San Francisco Peninsula and practically the whole of the Santa Lucia Range is granitic,[a] and granite also outcrops in the Mount Diablo Range. Granites are again found in the San Bernardino Mountains and in the Sierra Madre, and also in the highlands farther south. In these granitic mountain regions soil is almost entirely lacking and vegetation is restricted to a very scant growth of stunted shrubs. The sandstones of the area are usually massive and are made from disintegrated but only slightly decomposed granitic rocks.

Overlying the basement rocks are sedimentary sandstones, shales, and conglomerates, with scattered deposits of limestones. Asphaltum and bitumen are of common occurrence. Lying unconformably above these sediments are recent sandstones, poorly cemented and easily weathered, and in places rich in iron. Other rocks occasionally found are basaltic and diabasic intrusives, with here and there a small ore deposit. Several beds of coal are found in the Mount Diablo Range.

The soil cover varies both in quantity and character. In the mountain regions it is frequently almost lacking, and where found is rather in the nature of a talus than a true soil. Lower down in the valleys are deeper soils, as a rule sandy, and in certain localities are adobe lands.

Forests are in general of small extent, although in several places along the extreme coastal ridges and in the San Bernardino Mountains good stands of timber are found. Estimates of the Forest Service of the Department of Agriculture place the total standing live timber of merchantable size as approximately 1,512,000 feet b. m. for the whole drainage area, or less than 1 per cent of the total for the State. At present there is in some localities a decided tendency toward eucalyptus culture, which may eventually have a very salutary effect upon the run-off of this region.

[a] A full description of this granite is given by A. C. Lawson in Bull. Dept. Geology Univ. California, vol. 1, No. 1, p. 9.

The population of the drainage area, based on figures of the California state board of health for 1907, is approximately 572,000. Of this population, about 40,000 are in San Diego County. San Benito County is the least populous in the region, the number of its inhabitants having been estimated at 6,788. In the valley of southern California the population is scattered over the whole region, centering in numerous small cities and towns and in the city of Los Angeles. In the remaining sections the coastal districts and river valleys only are well settled. The chief centers are San Diego, Oxnard, Ventura, Santa Barbara, San Luis Obispo, Paso Robles, Salinas, Monterey, Santa Cruz, Watsonville, Hollister, and Gilroy. Large areas of mountain and interior lands are practically without inhabitants.

Fruit growing is the chief business of the region, but cattle raising and dairying are important industries. The valley of southern California is concerned almost exclusively with citrus production; Nordhoff Valley, in Ventura County, is given over to orange groves; and the Pajaro and lower Santa Clara valleys and the coastal regions of Santa Cruz are devoted to the raising of apples. Walnuts and apples are grown extensively in the southern part of the region, and plums and prunes are of considerable importance in the northern part. Beet-sugar production is a large and profitable industry of the Salinas Valley.

Commerce is slight except by rail, as there are no really good harbors along this whole stretch of coast, although San Diego has a large and partially protected bay which, with proper sea wall and breakwater, would be a most valuable harbor.

MONTEREY BAY SUBDRAINAGE.

DESCRIPTION.

The first break in the coastal mountains south of San Francisco Bay occurs just south of the city of Santa Cruz, where an indentation in the coast line forms the dovetail-shaped Monterey Bay, into which drain several rivers of considerable importance. Through the gap in the mountains Pajaro River discharges the waters of San Benito River and of the several streams of the south Santa Clara Valley. North of this, at Santa Cruz, San Lorenzo River empties into Santa Cruz Harbor, and on the south Salinas River meanders through a fertile meadow land to the bay. Carmel River, although discharging its water into the smaller Carmelo Bay on the south instead of directly into Monterey Bay, is essentially a part of this drainage basin and will be considered with it.

SAN LORENZO RIVER.

DESCRIPTION.

San Lorenzo River rises on the upper slopes of the Santa Cruz Mountains, flows southward to southeastward for about 20 miles, and empties into the Pacific Ocean near the town of Santa Cruz.

In the upper part of its basin the bed rock is largely granite and is well covered with soil which supports a good growth of timber. In the lower reaches the stream crosses certain beds of shale and sandstone, from which it picks up a quantity of mineral matter. Numerous small tributaries drain into the San Lorenzo from the steep slopes at the sides of the basin, and almost all of these creeks carry water better than that of the main stream.

CHARACTER OF WATER.

Samples for this investigation were collected near the bridge at Big Trees, just below the town of Felton. No gagings are available. The results are shown in the accompanying analyses.

Mineral analyses of water from San Lorenzo River at Big Trees.

[Parts per million, unless otherwise stated.]

Date.		Turbidity.	Suspended matter.	Silica (SiO_2).	$Fe_2O_3+Al_2O_3$.	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Total solids.
From—	To—													
1906.	1906.													
Jan. 6	Jan. 10	.....	20	33	1.0	41	11.0	61	0.5	0.0	144	37	26	230
Jan. 11	Jan. 20	.....	1,200	29	1.8	31	6.3	16	3.8	.0	79	30	17	198
Jan. 21	Jan. 30	.....	72	28	.8	31	7.1	26	1.7	.0	100	41	18	152
Jan. 31	Feb. 9	.....	28	24	.8	36	.....	19	1.7	.0	118	34	22	238
Feb. 10	Feb. 19	.....	68	21	1.4	27	8.0	13	0.3	.0	109	39	24	208
Feb. 20	Mar. 1	.....	112	23	2.2	32	7.5	15	3.0	.0	99	39	17	170
Mar. 2	Mar. 11	.....	116	23	3.6	33	8.4	18	5.4	.0	102	39	16	186
Mar. 12	Mar. 21	.....	170	20	3.6	19	8.2	18	1.5	.0	87	39	30	216
Mar. 22	Mar. 31	.....	176	20	5.8	26	6.9	13	1.8	.0	82	34	12	204
Apr. 1	Apr. 10	.....	96	23	2.4	34	8.3	11	1.8	.0	99	36	14	202
Apr. 11	Apr. 20	.....	62	21	4.4	41	10	19	3.6	.0	121	40	18	208
Apr. 21	Apr. 30	.....	18	20	5.0	49	11	17	2.4	.0	156	48	22	276
May 1	May 10	.....	30	25	3.2	54	12	22	3.6	.0	169	50	26	278
May 11	May 20	.....	16	23	3.2	51	12	35	3.2	.0	170	47	29	288
May 21	May 31	.....	114	26	3.8	42	12	21	2.2	.0	141	44	26	250
June 1	June 10	.....	4	19	4.0	43	12	23	2.6	.0	142	45	25	254
June 11	June 20	.....	16	22	4.4	47	12	28	1.9	.0	157	46	24	264
June 21	June 30	.....	26	21	5.4	39	12	27	2.0	.0	162	47	32	260
					Fe.									
July 1	July 10	.....	.....	27	.10	48	11	16		.0	164	52	28	280
July 11	July 20	.....	60	27	.10	56	14	27		[b]5.5	162	58	31	280
July 21	July 31	.....	48	25	.07	46	10	34		.0	167	53	34	286
Aug. 1	Aug. 10	.....	Trace.	31	.05	54	11	27		[b]7.0	154	43	35	296
Aug. 11	Aug. 19	.....	.....	28	.10	59	11	42		.0	176	43	35	310
Aug. 21	Aug. 31	.....	18	21	.10	52	9.9	31		.0	166	40	36	274
Sept. 1	Sept. 10	.....	Trace.	25	.15	47	11	38		.0	167	39	36	288
Sept. 11	Sept. 20	.....	Trace.	26	.20	51	11	37		.0	164	38	38	284
Sept. 21	Sept. 30	.....	2	24	.20	54	0.3	43		.0	163	37	40	288
Oct. 1	Oct. 10	.....	38	21	.10	68	10	24		.0	189	39	41	260
Oct. 11	Oct. 20	.....	Trace.	17	.05	48	9.5	44		.0	184	44	41	288
Oct. 21	Oct. 31	.....	16	20	.10	44	9.7	32		.0	182	37	40	284
Nov. 1	Nov. 10	.....	36	20	.30	46	9.8	37		.0	174	44	40	306
Nov. 11	Nov. 20	5	44	23	.70	56	11	41		.0	182	44	41	286
Nov. 21	Nov. 30	5	6	25	.50	51	12	43		.0	186	50	41	280
Dec. 1	Dec. 10	10	28	19	.07	48	11	46		.0	182	52	39	310
Dec. 11	Dec. 19	60	134	16	.10	40	8.9	32		.0	128	42	28	234
Dec. 21	Dec. 31	40	66	15	.20	37	9.8	32		.0	128	46	31	262
Mean		.....	84	23	[a].18	44	10	31		.0	147	43	29	255
Per cent of anhydrous residue		.....	.....	9.1	0.1	17.4	3.9	12.5		28.5	.....	17	11.5	.....

[a] Mean of Fe values after July 1. [b] Abnormal. Computed as HCO_3 in the average.

The water from this river is not used in any manufacturing establishment, that from the smaller creeks being preferred. The city of Santa Cruz is furnished with water from these creeks. Two important industries are located in this basin, the California Powder Works and the plant of the Kron Tanning Company, both a short distance above Santa Cruz. No nitrating is done at the powder works, and there is therefore little or no acid waste to pollute the stream. The wastes from the tannery consist of spent liquors and washing from the hides, which are run into sedimentation basins alongside the river; from these the leachings eventually reach the stream. As both of these industries are located below the point at which the samples were taken, the effects of pollution, if any, do not appear in the tabulated analyses.

In the basin above the sampling station are several small towns, for the most part summer colonies. It is probable that considerable sewage and house drainage finds its way into the river at certain seasons of the year, rendering its water unfit for use. Otherwise the water is clear and free from objectionable mineral substances. In order to use the water successfully in boilers or for other industrial purposes for which a hard water is unsuited, it should be treated with soda ash or some similar softening compound to remove the excess of lime and magnesia. As these exist principally as the bicarbonates, the process of softening the water would be comparatively simple. Altogether this river is representative of the better class of coast streams, which for the most part drain areas in which shale and sandstone abound.

SALINAS RIVER SYSTEM.

DESCRIPTION.

The Salinas Valley extends from the Santa Lucia Mountains northwestward for about 150 miles to Monterey Bay. It is walled in on the northeast by the Mount Diablo and Gabilan ranges, which separate it from the San Joaquin and San Benito valleys, and on the southwest by the Santa Lucia Mountains and the Sierra del Salinas, which, respectively, shut it off from the Pacific Ocean and the Carmel Valley. Smaller valleys join it at intervals from both sides and combine to give its total drainage an area of 4,780 square miles.[a] The valley is narrow and winding in its upper stretches, but broadens out below the town of Bradley to an average width of 20 miles. Above Soledad it again narrows sharply, its average width at that point being about 5 miles. Nearing Monterey Bay it spreads out again into a broad, fertile coastal valley. Throughout its extent it is traversed by Salinas River.

[a] Hamlin, Homer, The water resources of Salinas Valley, California: Water-Supply Paper U. S. Geol. Survey No. 89, 1904, p. 10.

The valleys to the southwest of the main valley are fewer than those on the east, but they are in general well defined. In their bottoms are important creeks, and as assets they far outrank their northeastern complements. The latter are, with two exceptions, of little importance, containing only short mesa streams of torrential character. The difference between these two sets of tributary valleys is marked not only by the character and importance of their streams, but by the casual conditions of climate, rainfall, and forest covering. From north to south the tributary streams are as follows:

Principal tributaries of Salinas River.

Southwestern tributaries.	Northeastern tributaries.
Arroyo Seco.	Gabilan Creek.
San Antonio River.	Chalone Creek.
Nacimiento River.	San Lorenzo Creek.
San Marcos Creek.	Gaviota Creek.
	Bitterwater Creek.
	Indian Valley Creek.
	Estrella River:
	Cholame Creek.
	San Juan Creek.
	Huer Huero Creek.

The soil of the Salinas Valley is the disintegration product of the underlying rock and hence is principally sand. In places, owing to the slight decomposition of the original rock materials and to the semiaridity of the climate, the loose sandy soil is rich in feldspar and magnesium salts and is very fertile and rich. In other places, chiefly near the head of the valley proper, adobe soils occur. At present, as a result of injudicious methods of agriculture formerly used in this section, large tracts of land are unutilized and considerable reclamation work will be necessary in these regions to render farming productive. One important factor in deciding the crop-producing value of the lands, especially in the central and upper valley, is the wind. The loose, sharp sand of the river bottom is blown about by the strong northwest winds of summer and spreads over the surrounding country in rolling dunes, choking vegetation and giving to small areas the appearance of a desert.

Agriculture is the chief industry in the valley, but cattle raising holds an important position, the hills, useless for other purposes, being devoted to grazing. Oats and barley are the principal crops and alfalfa is extensively cultivated. In the lower central valley the raising of sugar beets holds an important position. The whole beet crop of the section is used by a large refinery at Spreckles, 4 miles up the valley from Salinas City. Nearer the mouth of the river dairying is an extensive industry, the products being marketed chiefly in San Francisco and the Bay cities.

At Stone Canyon, in the mountains above the town of Bradley, is a coal deposit of some local importance. The coal is said to be of good grade.

SALINAS RIVER.

DESCRIPTION.

Salinas River rises on the northeastern slopes of the Santa Lucia Range, in the region of the heaviest rains in these mountains, flows in a general northwesterly course and discharges its waters into Monterey Bay. The valley slopes of the upper reaches of the basin are well forested and the river has a large winter flow and moderate summer flow. It receives many small tributaries, the most important of which are listed on page 69.

CHARACTER OF WATER AT SPRECKLES.

Salinas River near Spreckles's sugar refinery above Salinas City is a broad, shallow stream meandering through a flat bottom land of loose, coarse sand interspersed with finer quicksands. The following table shows the estimated monthly discharge of the river for 1900 and part of 1901:[a]

Estimated monthly discharge of Salinas River 4 miles south of Salinas.

[Drainage area, 4,084 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1900.						
January 8–31	2,700	223	848	40,368	0.21	0.19
February	223	40	105	5,831	.03	.03
March	223	25	73	4,489	.02	.02
April	32	19	22	1,309	.01	.01
May	19	17	17	1,045	.00	.00
June	17	15	16	952	.00	.00
July	10	6	8	492	.00	.00
August	8	6	7	430	.00	.00
September	8	2	6	357	.00	.00
October	4	1	2	123	.00	.00
November	33,600	0	2,413	143,583	.59	.66
December	1,050	82	295	18,139	.07	.08
1901.						
January	35,162	380	4,921	302,580	1.21	1.39
February	20,927	540	4,131	231,701	1.02	1.06
March	1,772	430	1,063	65,361	.26	.30
April	405	160	270	16,066	.07	.07
May	2,012	160	533	32,773	.13	.15
June	160	30	56	3,332	.01	.01
July	30	25	27	1,660	.01	.01

[a] Hamlin, Homer, The water resources of Salinas Valley, California: Water-Supply Paper U. S. Geol. Survey No. 89, 1904, p. 48.

Samples of water collected at this point on April 6 and August 28, 1908, were analyzed, with the results shown in the accompanying table.

Analyses of waters of the Salinas River system.

[Collected and analyzed by Walton Van Winkle. Quantities in parts per million.]

	Salinas River at Spreckels's sugar refinery.		Gaviota Creek 1 mile above San Ardo.	San Lorenzo Creek at Matthews dam site.	
	Apr. 6, 1908.	Aug. 28, 1908.	Apr. 7, 1908.	Apr. 7, 1908.	Aug. 25, 1908.
Turbidity	20	10	Trace.	5	6
Silica (SiO_2)	28	25	102	23	24
Iron (Fe)	.15	.23	.38	.25	.15
Calcium (Ca)	66	72	286	167	159
Magnesium (Mg)	31	50	152	181	174
Sodium (Na)	51	70	402	617	725
Potassium (K)			17	39	46
Carbonate radicle (CO_3)	24	8.4	12	37	24
Bicarbonate radicle (HCO_3)	181	249	164	261	287
Sulphate radicle (SO_4)	150	253	1,848	1,793	1,728
Chlorine (Cl)	49	80	161	432	506
Nitrate radicle (NO_3)	1.3	1.0	1.0	39	.8
Total solids	501	781	3,231	3,689	3,653

	Indian Valley Creek at Douglas ranch.		Cholame Creek at Shandon.		San Juan Creek at Shandon.		Huer Huero Creek near Paso Robles.
	Apr. 8, 1908.	Aug. 25, 1908.	Apr. 9, 1908.	Aug. 24, 1908.	Apr. 9, 1908.	Aug. 24, 1908.	Apr. 9, 1908.
Turbidity	10	8	Trace.	5	10	9	Trace.
Silica (SiO_2)	28	43	14	27	31	41	35
Iron (Fe)	.18	.15	.18	.20	1.0	.15	.18
Calcium (Ca)	126	145	110	73	94	59	59
Magnesium (Mg)	81	86	100	101	35	24	21
Sodium (Na)	106	164	487	486	163	112	82
Potassium (K)	72		56	55	45	31	
Carbonate radicle (CO_3)	12	0.0	0.0	20	7.2	.....	14
Bicarbonate radicle (HCO_3)	259	437	324	159	201	124	281
Sulphate radicle (SO_4)	644	611	836	891	403	272	55
Chlorine (Cl)	63	74	508	533	236	131	71
Nitrate radicle (NO_3)	.....	2.0	.4	.7	.3	1.0	1.0
Total solids	1,316	1,352	2,354	2,332	1,031	746	451

The water is distinctively that of an arid region. The sulphate is the predominating acid radicle, carbonates ranking second. The chief basic constituent is calcium, the alkalis showing values almost as high. Magnesium is relatively high, the ratio of this element to calcium being, for the two analyses, 1 to $2\frac{1}{8}$ and 1 to $1\frac{4}{9}$. The normal carbonate radicle is present in large quantities, as is also the bicarbonate radicle. Chlorine is relatively low, averaging about 10 per cent, while the sulphate radicle forms about 30 per cent of the total dissolved matter.

The water is unfit for domestic or boiler use without treatment. Its high sulphate, carbonate, and sodium contents make it doubtful whether it could be safely used for irrigation. As all water taken from the river at this point would have to be pumped to the land on which it would be used, it is extremely improbable that it will be extensively applied in irrigation.

CHARACTER OF WATER AT PASO ROBLES.

Near Paso Robles the upper Salinas flows through a broad, rolling country with considerable covering of oak. The drainage area at this point is about 400 square miles.[a] The river here is practically perennial, but unfortunately there was no surface flow during the summer of 1908. No gage records were kept during the year, but the general conditions may be stated.

The greatest discharge occurred in January, February, and March; following this was a period of drought, during which the river gradually subsided, surface flow ceasing entirely on July 17, and from this time until October the river was dry. From October 1 until December the stream flow was slight and was produced almost entirely by rainfall in the Santa Lucia Mountains. During December rain occurred in the valley proper and the stream began to rise to winter conditions.

Samples of water were collected daily during the periods of flow, at first by C. B. Weiser, of the local water company, and later in the spring by J. M. Currell.

[a] Planimeter measurement on United States Land Office map.

Mineral analyses of water from Salinas River at Paso Robles.

[Parts per million unless otherwise stated.]

Date.		Turbidity.	Suspended matter.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.
From—	To—													
1907.	1908.													
Dec. 31	Jan. 9	Trace.	.....	27	0.53	83	27	37	2.4	246	99	0.5	25	415
1908.														
Jan. 10	Jan. 19	Trace.	.....	24	.02	65	27	33	1.2	249	103	1.8	25	423
Jan. 20	Jan. 29	175	249	25	.50	55	20	16	.0	183	80	1.2	17	307
Jan. 30	Feb. 8	50	62	34	.25	45	19	26	.0	168	72	.6	15	292
Feb. 9	Feb. 18	65	88	29	.35	44	21	30	2.4	173	74	1.3	14	296
Feb. 19	Feb. 28	50	32	28	.07	53	24	29	9.6	188	87	.81	18	334
Feb. 29	Mar. 9	60	92	26	.20	45	22	25	.0	185	83	.94	16	315
Mar. 10	Mar. 19	10	.....	30	.30	55	25	28	7.2	215	96	.88	21	352
Mar. 20	Mar. 29	Trace.	.....	26	.30	57	24	33	1.2	222	97	1.5	22	380
Mar. 30	Apr. 8	Trace.	.....	27	.16	61	28	34	11	221	101	1.2	22	387
Apr. 9	Apr. 18	5	.....	25	.08	60	26	33	.0	246	106	1.0	23	388
Apr. 19	Apr. 28	5	.....	25	.18	61	27	32	12	229	98	.80	23	391
Apr. 29	May 8	Trace.	.....	30	.05	60	28	32	12	229	99	1.0	24	391
May 9	May 18	Trace.	.....	32	.03	61	33	35	17	222	98	.60	25	408
May 19	May 28	Trace.	.....	30	.15	65	30	41	31	198	103	1.5	29	428
May 29	June 7	5	.....	27	.05	64	28	51	9.1	255	100	.80	33	426
June 8	June 17	Trace.	.....	24	.20	54	23	53	19	245	87	.62	37	427
June 18	June 27	Trace.	.....	28	.05	63	30	66	2.6	305	97	1.2	51	466
June 28	July 7	Trace.	.....	30	.19	61	29	83	4.3	312	95	.48	56	475
July 8	July 17	3	.....	37	.10	65	30	79	1.2	339	116	.34	65	537
Oct. a1	Oct. 5	Trace.	.....	36	.02	57	31	88	2.4	326	103	.5	65	530
Oct. 6	Oct. 15	Trace.	.....	42	.07	62	36	103	4.8	349	106	.4	63	544
Oct. 16	Oct. 25	Trace.	.....	46	.04	60	32	99	6.0	344	99	.48	64	545
Oct. 26	Nov. 4	Trace.	.....	35	.05	63	32	108	3.6	353	95	.30	63	540
Nov. 5	Nov. 14	5	.....	35	.05	64	32	84	2.4	351	94	.24	62	544
Nov. 15	Nov. 24	6	.....	33	.04	65	32	90	.0	354	98	.18	60	537
Nov. 25	Dec. 4	5	.....	29	.08	64	34	93	.0	354	111	.18	60	555
Dec. 5	Dec. 14	Trace.	.....	33	.12	66	32	89	4.8	332	106	.40	56	615
Dec. 15	Dec. 24	Trace.	.....	35	.06	65	31	92	.0	354	104	.40	57	540
Dec. 24	Dec. 31	35	5.6	36	.08	63	36	126	.0	400	110	.18	64	648
Mean		16	.....	31	.15	60	28	59	5.6	272	97	.74	39	448
Percent of anhydrous residue		.....	.....	6.8	0.0	13.2	6.2	13.0	30.7	.....	21.3	0.2	8.6	.....

[a] River dry July 18 to October 1.

The most striking feature shown by the series of analyses is the remarkable increase in total dissolved material at the close of the year. From December, 1907, when the first samples were collected, until the river ceased flowing in the summer of 1908 the total dissolved material varied inversely with the stream flow, falling to 296 parts per million for the period from January 30 to February 8, inclusive, and slowly and gradually rising from that time on until the river ceased flowing, when the total dissolved matter was 537 parts per million. When the stream began flowing above ground in October this value remained practically constant until the first part of December. With the first rainfall of the year the dissolved material, instead of falling with the flood conditions, rose rapidly until the last sample taken showed a value of 648 parts per million. This rise, although at first appearance abnormal, is entirely in accordance with what might be expected in a stream in a semiarid region. During the drought of the summer the amount of soluble material in the soil due to weathering of the rocks and to other

causes accumulates and lies ready to be washed into the rivers by the first rainfall. Thus with the first general rains of the winter, the dissolved material, instead of falling off, as during flood conditions in most seasons, rises constantly, and it falls again only when the surface of the drainage basin has been scoured by these early rains. Had the analyses been continued until the later floods of the winter of 1908–9, a constant decrease in the quantity of total dissolved material would have appeared, so that in January and February the figures for this would have been considerably less than 300 parts per million. As great floods occurred in the later winter of 1908–9, the decrease in dissolved material would probably have been very marked.

The water is calcic carbonate in type, but sulphates are important constituents. The alkalis, sodium and potassium, are relatively unimportant until after the drought of the summer, but following the first run-off of the next wet season they are greater than all other bases. This increase in sodium is accompanied by a corresponding though somewhat smaller increase in chlorine.

The water is not well suited for municipal use except at high stages of the river. Its use in the laundry will entail a large expense for soap. In boilers and in the engine its use will be accompanied by the formation of scale. Much of the hard scale can, however, be prevented by chemical treatment. Corrosion of boilers and of kitchen utensils may result from the excessive content of chlorides and nitrates in the water, but this can not be prevented by any chemical process. If the water should be used for municipal supply, therefore, proper storage facilities should be provided so that the flood discharge may be impounded and used throughout the year. No manufacturing plant which uses water as an essential element of its process can use the water of Salinas River with impunity, and the same may be said of all the waters in the Salinas drainage basin.

SAN LORENZO CREEK.

DESCRIPTION.

San Lorenzo Creek rises in the western slopes of the Mount Diablo Range. It is formed by the junction of two small streams, one flowing southeastward through a narrow valley for about 15 miles, the other, Lewis Creek, flowing northeastward from the head of Priest Valley in the Mount Diablo Range. The united waters flow southwestward to Salinas River, having received Peachtree Creek about 5 miles below their junction. The total drainage area of San Lorenzo Creek at the Matthews dam site, about 6 miles northeast of Kings City, is 235 square miles.[a] The stream is torrential, having a large winter flow and being almost dry in summer.

[a] Water-Supply Paper U. S. Geol. Survey No. 89, p. 69 et seq.

CHARACTER OF WATER.

Samples of water were collected from San Lorenzo Creek at Matthews dam site on April 7 and August 25, 1908. The analyses of these samples (see table on p. 71) show this stream to be heavily charged with dissolved mineral matter. Although one sample was taken shortly after the last of the winter rains and the other at the height of the dry season, the analyses show little difference in the quantity of matter in solution. The first sample yielded on evaporation 3,689 parts per million of dissolved matter, and the last 3,653 parts. The chief constituents of this dissolved matter are sodium and sulphates. The alkalies form over two-thirds of the total basic constituents, and on evaporation the water yields large quantities of sodium sulphate or white alkali. In the dry season this appears along the banks of the stream as a frothy effervescence on the rocks and soil. Qualitative analysis of a sample collected August 25, 1908, showed it to be almost pure sodium sulphate.

Normal carbonates are present in large amounts, and, however small their relative proportion, they can not be neglected. No permanently successful irrigation can be carried on with water of this character, and the ground over which it is poured will soon become fit for little else than salt grass, as the minerals dissolved in it are toxic to plant life.

The water is unfit for use in boilers because of its permanent hardness and its tendency to foam and to cause corrosion, and chemical treatment would not render it suitable. Its soap-consuming power is excessive, food cooked in it would lose in flavor and nutrient value, and persons drinking it would probably be unpleasantly affected.

GAVIOTA CREEK.

DESCRIPTION.

Gaviota or Poncha Rica Creek rises in the Mount Diablo Range, its headwaters being separated from those of Cholame Creek by a narrow divide. It flows through a deep canyon for about 10 miles in a northwesterly direction, and then, turning to the southwest, passes through the mesas to Salinas River near San Ardo. It is a torrential stream, with no summer flow in its lower reaches.

CHARACTER OF WATER.

A sample was taken from this creek about 1 mile above San Ardo on April 7, 1908, when the stream was at low stage. In August, 1908, when the creek was revisited, its bed was dry.

The analysis (see table on p. 71) shows that the water of this creek is of very different type from that of San Lorenzo Creek. Although the total dissolved matter is but slightly less, the percentage composition differs radically. The alkalies are present in amounts about equal to the alkaline earths, carbonates are present

in small amounts only, and chlorine appears in about one-third the relative quantity found in San Lorenzo Creek. Silica is high, showing a value of more than 100 parts per million.

This water is unfit for irrigation, steaming, or domestic use. If used in irrigation it would saturate the soil with white alkali; in boilers it would cause corrosion, scale, and foaming, and treatment would not materially improve it. Its soap-consuming power is prohibitive. Taken internally its use would be attended with intestinal disorders.

INDIAN VALLEY CREEK.

DESCRIPTION.

Indian Valley Creek rises in the Mount Diablo Range in the vicinity of Stone Canyon and flows southwestward through a broad, deep valley to Salinas River, which it enters about 4 miles below San Miguel. In summer it is a mere trickling rivulet, but in winter it has the torrential character of all the streams of the region. The coal mine at Stone Canyon is the one feature that gives importance to the creek. No good reservoir sites are found on the middle or lower reaches of the creek.

CHARACTER OF WATER.

Samples of water were taken from Indian Valley Creek on April 8 and August 25, 1908.

The analyses (p.71) show the water to be much better than that of the other streams on the northeast side of the Salinas Valley. Total dissolved solids were, in one sample, 1,316 parts per million, and in the other 1,352 parts per million. The principal difference is in the amount of white alkali, as sodium and potassium together are present in about one-fourth the amount found in San Lorenzo Creek and about two-fifths that found in Gaviota Creek. The sulphate radicle predominates among the acids, carbonates being the acid element of second importance. Calcium is almost as high in value as the alkalies, the alkaline earths together being much greater in amount than the alkalies themselves.

Although the water is far superior to that of either San Lorenzo or Gaviota Creek, it is unfit for ordinary domestic or industrial use, and treatment would not materially improve it. In irrigation it might be used successfully if the greatest care and the most scientific methods were employed.

ESTRELLA RIVER.

DESCRIPTION.

Estrella River is formed by the union of San Juan and Cholame creeks. San Juan Creek rises near the head of Carrizo Plain, and, skirting its western edge, traverses a broad valley northward to Shandon, where it meets Cholame Creek, which rises in the Mount Diablo Range and flows southward through a narrow, barren valley. From Shandon the Estrella flows northwestward among rolling hills,

uniting with Salinas River at San Miguel, at which place its drainage area comprises 924 square miles.[a] The country through which it passes is semiarid and the soil is sandy, being formed from the disintegration of sandstones and shales.

CHARACTER OF WATER.

Single samples were taken from San Juan and Cholame creeks at Shandon in April and August, 1908, and daily samples were taken from Estrella River near San Miguel throughout the year by J. A. Journey. As the greater part of the water of Estrella River is derived from the combined discharges of the creeks, the characteristics of the creek waters will be discussed first.

Mineral analyses of water from Estrella River near San Miguel.

[Drainage area, 924 square miles. Quantities in parts per million unless otherwise stated.]

Date.		Turbidity.	Suspended matter.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.
From—	To—													
1907. Dec. 31	1908. Jan. 9	30	40	35	0.08	86	49	221	4.8	278	336	0.4	185	1,094
1908. Jan. 10	Jan. 19	50	6	30	.30	80	47	202	4.8	273	345	.24	180	1,084
Jan. 20	Jan. 29	1,800	2,890	38	.30	94	47	155	0	232	299	2.0	145	926
Jan. 30	Feb. 8	950	1,631	28	.12	95	35	173	0	212	350	.26	146	955
Feb. 9	Feb. 18	1,200	1,889	24	.28	90	36	147	0	206	304	1.3	112	925
Feb. 19	Feb. 28	550	853	28	.08	90	48	189	0	240	394	1.0	160	1,039
Feb. 29	Mar. 9	750	910	26	.22	90	40	150	0	292	341	4.0	121	889
Mar. 10	Mar. 19	85	101	31	.32	86	47	195	5.0	266	391	.80	157	1,060
Mar. 20	Mar. 29	5	.....	33	.05	86	49	208	14.0	264	403	.92	171	1,117
Mar. 30	Apr. 8	5	.....	37	.15	86	54	212	19	257	408	.95	185	1,140
Apr. 9	Apr. 18	5	.....	31	.05	80	55	216	17	254	408	.65	193	1,167
Apr. 19	Apr. 28	20	24	33	.33	80	55	219	17	261	408	.90	195	1,162
Apr. 29	May 8	Trace.	.....	29	.08	79	56	223	17	261	393	.65	199	1,176
May 9	May 18	Trace.	.....	36	.15	77	58	229	8.4	276	422	1.4	214	1,229
May 19	May 28	Trace.	.....	40	.35	71	60	247	16	254	444	1.5	223	1,281
May 29	June 7	15	.....	26	.08	83	62	259	0	408	383	.34	216	1,233
June 8	June 17	10	.....	38	.29	98	75	276	0	394	480	1.6	252	1,433
June 18	June 27	Trace.	.....	32	.14	68	54	230	18	230	387	.80	174	1,099
June 28	July 7	5	.....	52	.18	69	56	243	19	229	406	.36	206	1,149
July 8	July 17	Trace.	.....	42	.15	71	54	250	20	232	418	.34	217	1,182
July 18	July 27	5	.....	37	.45	70	60	266	22	245	427	1.4	228	1,254
July 28	Aug. 6	Trace.	.....	38	.08	74	59	254	19	259	404	.44	224	1,210
Aug. 7	Aug. 16	6	.....	38	.35	64	60	298	19	243	425	1.6	252	1,345
Aug. 17	Aug. 26	5	.....	34	.15	66	62	266	17	246	426	.50	234	1,243
Aug. 27	Sept. 5	15	27	38	.28	64	59	275	19	236	417	1.1	241	1,211
Sept. 6	Sept. 15	Trace.	.....	36	.08	65	57	250	11	246	418	1.3	223	1,189
Sept. 16	Sept. 25	30	54	37	.15	73	55	235	0	289	455	.18	206	1,198
Sept. 26	Oct. 5	60	83	39	.08	80	55	235	8.4	304	397	.02	195	1,200
Oct. 6	Oct. 15	50	67	40	.18	76	57	218	9.6	310	371	.60	197	1,156
Oct. 16	Oct. 25	45	71	38	.11	80	54	244	7.2	327	381	.70	200	1,180
Oct. 26	Nov. 4	30	27	34	.45	79	56	239	11	315	359	.70	192	1,119
Nov. 5	Nov. 14	70	86	43	.12	81	53	223	9.6	310	356	.40	188	1,131
Nov. 15	Nov. 24	30	81	45	.08	75	51	218	11	292	334	.60	181	1,079
Nov. 25	Dec. 4	40	83	31	.14	69	52	210	2.4	298	348	.92	177	1,039
Dec. 5	Dec. 14	70	122	32	.36	78	46	211	4.8	283	336	.88	177	1,009
Dec. 15	Dec. 24	25	60	29	.13	77	44	195	0	293	324	.60	167	961
Dec. 25	Dec. 31	9	.....	32	.10	80	52	216	4.8	276	334	.60	167	978
Mean.....		161	.....	35	.19	79	53	224	9.6	273	385	.88	192	1,131
Per cent of anhydrous residue..		.....	.....	3.1	0.0	7.1	4.8	20.1	12.9	.....	34.6	0.1	17.3	.....

[a] Hamlin, Homer, The water resources of Salinas Valley, California: Water-Supply Paper U. S. Geol. Survey No. 89, 1904, p. 49.

It is evident from the analyses (p. 71) that the two streams differ radically in the quantity and character of the dissolved mineral matter. The water of San Juan Creek, containing about one-half as much mineral matter in solution as Cholame Creek, is distinctively a sodic sulphated type, calcium being the second most prominent base and chlorine the second most important acid element. The water of Cholame Creek, on the other hand, is almost as highly impregnated with magnesium as with calcium, and one analysis shows magnesium greater. In San Juan Creek potassium is in excess of magnesium; in Cholame Creek the potassium content is only half as great as the magnesium. Carbonates are relatively unimportant in both streams, although the waters of both show at times some normal carbonates. Both are good types of arid region waters and their use is of necessity restricted to irrigation. Even for that use the waters might at times do as much harm as good, although that of the San Juan, if judiciously applied, can probably always be used to advantage.

The result of the blending of these two waters appears in Estrella River, the analyses showing strongly the sodium sulphated character of both. Chlorine is the second ranking acid element, and calcium is second among the bases. Magnesium, although its percentage is small, is present in large quantities, measured absolutely. Nitrates are usually small, but at times are quite high. Normal carbonates are present in considerable amount. Total solids are commonly high, showing a tendency to rise slightly throughout the dry season and to decrease correspondingly during the winter. The heavy floods of January, February, and March are marked by considerable variation in dissolved material and by extreme turbidity. The barren nature of the San Juan, Cholame, and Estrella valleys and the adobe-like character of the top soil combine to produce conditions of decided turbidity after rains. Thus in the flood discharge of January 20 to 30, 1908, the average turbidity for the ten days was 2,890 parts per million, or 784 pounds per acre-foot discharge.

The water of all three streams is unfit for steaming or municipal use. Cholame Creek is unfit for irrigation, but San Juan Creek may be used to advantage if the winter flow can be stored and used in the dry season or if suitable methods are employed.

Estrella River water is also unsuited for irrigation unless rigidly scientific methods are employed, for its use will be attended by the deposition of white alkali and, at times, of considerable black alkali.

HUER HUERO CREEK.

DESCRIPTION.

Huer Huero Creek is tributary to the Salinas south of San Miguel. Its drainage area, approximately 150 square miles [a] in extent, consists of rolling country, partly oak covered and partly under cultivation.

[a] Planimeter measurement on United States Land Office map.

CHARACTER OF WATER.

A single sample of water was taken from Huer Huero Creek on April 9, 1908, at the ford on the Creston road. At this time there was a very good flow, but in August, when the locality was revisited, the bed was dry.

The water of this creek is shown by the analysis (p. 71) to be entirely different in character from that of the streams of the Estrella River valley. It contains only 451 parts per million of dissolved minerals, and chief among its constituents are, not sodium and sulphates, but sodium and bicarbonates. Normal carbonates are present, and the evaporation of the water would tend to produce black alkali, but the amount of white alkali is small.

The stream is unimportant, but it may find use locally for irrigation, for which its water is fairly well adapted.

ARROYO SECO.

DESCRIPTION.

Arroyo Seco, the most northerly of the tributaries of Salinas River, rises in the Santa Lucia Range, one of the smaller groups which go to make up the Coast Range, and flows in a general northeasterly direction to join the Salinas near Soledad. The upper valleys of this stream are far back in the range, surrounded by high mountains.

The drainage area of Arroyo Seco is made up almost entirely of steep ridges and canyons. The western part is well covered with brush and trees of moderate size, but this growth decreases toward the east until at the Salinas Valley the country is quite bare. The stream bed falls rapidly from an elevation of about 6,000 feet above sea level at its source to about 170 feet at its mouth. The stream is torrential in character, the flow being extremely high during winter and early spring and dwindling to almost nothing later in the season.

The basin is very sparsely settled, there being only a few towns of scarce a hundred population. The main industries are farming and stock raising.

CHARACTER OF WATER.

Samples of water for this investigation were collected by the gage reader at the gaging station near Pettitt's ranch, above Soledad.[a] The stream at this point flows between high rocky banks and its bed is composed of rock and gravel.

The floods of winter and early spring are accompanied by increases in the quantity of matter carried by the stream in suspension. Later

[a] For data concerning the gage heights and discharge of this stream see Water-Supply Papers U. S. Geol. Survey Nos. 81, 100, 134, 177, and 213.

in the season, as the flow diminishes, the water becomes almost limpid.

The water is essentially of the carbonate type, calcium and magnesium predominating in the basic matter. The total amount of mineral matter is fairly high, although not as compared with that of some of the other streams in the Salinas basin.

The water from Arroyo Seco is used for irrigation in the lower valley, canals and intakes being constructed to divert the water before it reaches the broad, level valley of the Salinas. Numerous reservoir sites have been surveyed on this watershed and on the tributaries with the object of storing the flood waters, but as yet the water has not been used except for irrigation.

Mineral analyses of water from Arroyo Seco at Soledad.

[Parts per million unless otherwise stated.]

Date.		Turbidity.	Suspended matter.	Silica (SiO_2).	$Fe_2O_3+Al_2O_3$.	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Total solids.	Mean discharge.	
From—	To—														Acre-feet per day.	Cubic feet per second.
1906.	1906.															
Jan. 1	Jan. 9	....	22	29	4.0	53	14	29	3.1	0.0	176	70	11	304	254	128
Jan. 11	Jan. 20	....	202	23	1.0	29	7.4	18	2.7	.0	95	40	8.8	140	2,367	1,194
Jan. 21	Jan. 30	....	38	26	1.6	32	7.6	29	3.6	.0	111	37	7.4	158	764	385
Jan. 31	Feb. 9	....	16	26	1.4	25	5.4	14	1.6	.0	134	21	14	226	281	142
Feb. 10	Feb. 18	....	44	21	1.6	35	8.5	7.1	1.7	.0	118	40	11	156	625	315
Feb. 25	Mar. 1	....	74	23	2.0	35	10	7.2	2.7	.0	114	37	9.5	132	807	407
Mar. 2	Mar. 10	....	30	26	2.8	33	9.1	12	1.7	.0	111	38	14	176	1,186	598
Mar. 12	Mar. 21	....	222	18	2.8	28	7.5	8.0	1.3	.0	93	32	15	178	3,764	1,898
Apr. 1	Apr. 10	....	16	19	4.2	35	8.4	16	3.1	.0	107	17	11	180	1,850	933
Apr. 11	Apr. 20	....	36	25	4.6	40	11	13	2.4	.0	126	43	7.8	200	823	415
Apr. 21	Apr. 27	....	.....	30	2.0	42	11	15	1.7	.0	134	51	9.8	234	676	341
May 4	May 10	....	26	27	4.0	48	12	16	2.4	.0	154	62	12	238	419	211
May 11	May 20	....	12	28	2.0	51	13	21	2.2	.0	155	59	11	254	355	179
May 21	May 31	....	.....	20	3.2	40	13	12	1.9	.0	131	52	12	230	1,024	516
June 1	June 10	....	Trace.	26	5.0	41	11	20	2.2	.0	137	46	9.0	246	510	257
June 11	June 20	....	.....	32	3.6	53	14	18	1.8	.0	154	60	12	262	319	161
June 21	June 30	....	14	27	5.6	51	19	26	4.6	.0	161	65	14	264	230	116
					Fe.											
July 1	July 10	....	26	22	.7	45	16	25		.0	158	68	13	276	380	192
July 11	July 20	....	Trace.	25	.10	72	15	26		.0	184	75	13	320	910	459
July 21	July 31	....	22	24	.10	59	16	31		.0	193	87	16	320	649	327
Aug. 1	Aug. 10	....	12	34	.13	65	17	48		.0	207	102	14	270	48	24
Aug. 11	Aug. 20	....	18	33	.10	75	18	49		.0	214	104	15	384	32	16
Aug. 21	Aug. 31	....	8	29	.15	61	18	40		.0	211	105	11	370	24.6	12.3
Sept. 1	Sept. 10	....	20	29	.20	63	19	24		.0	217	110	17	402	2.58	1.3
Sept. 11	Sept. 20	....	16	29	.10	71	19	50		[a]5.0	210	114	19	414	8.93	4.5
Sept. 21	Sept. 30	....	20	28	.10	74	19	48		.0	255	120	11	408	40.7	20.5
Oct. 1	Oct. 10	....	6	30	.10	66	20	54		.0	244	127	19	440	21.2	10.7
Oct. 11	Oct. 20	....	24	27	.05	68	19	48		.0	258	117	20	424	24.8	12.5
Oct. 21	Oct. 31	0	4	23	.15	68	20	52		.0	258	119	18	420	36.7	18.5
Nov. 11	Nov. 20	2	8	28	.7	61	17	42		.0	238	107	16	386	47.6	24.0
Nov. 21	Nov. 30	2	18	26	.15	68	18	40		.0	238	107	18	362	63.5	32.0
Dec. 1	Dec. 10	2	Trace.	24	.10	66	18	43		.0	225	103	18	366	77.5	39.0
Dec. 11	Dec. 20	10	32	18	.30	40	9.1	32		.0	128	47	10	214	2,050	1,034
Dec. 21	Dec. 30	30	46	20	.07	32	9.4	22		.0	113	54	10	196	8,184	4,126
Mean		....	33	26	[b].20	51	14	29		.0	170	72	13	284	849	428
Per cent of anhydrous residue		....	.....	9.0	0.1	17.6	4.9	10.0		29.0	....	24.9	4.5	....	.....	.....

[a] Abnormal; computed as HCO_3 in the average.

[b] Mean of Fe values after July 1.

SAN ANTONIO RIVER.

DESCRIPTION.

San Antonio River rises in the Santa Lucia Mountains directly south of Santa Lucia Peak, which separates its drainage basin from that of Arroyo Seco. Flowing to the southwest in a rather narrow oak-studded valley, it leaves the mountains near the town of Jolon and enters there a series of broad valleys with sandy soil covering, through which it winds it way to the Salinas. Its total drainage area is estimated to be 340 square miles.[a] During the summer season this river has no surface flow in its lower course, although its subsurface flow is probably good.

CHARACTER OF WATER.

Samples of water for this investigation were collected daily during 1908 by Andrew Branch at Branch's ranch house, near the Pinkerton dam site, where the river flows through a narrow pass between sandstone hills. The bed of the stream at this point is sand to about 25 feet thick, and there is surface flow during the greater part of the year. In the dry season and even in the driest years water may always be found within a foot to 18 inches of the surface. During the last part of 1908 the river bed was dry and the samples for analysis were obtained by digging a hole in the sand bed until the underflow water was tapped. The drainage area of the river at the dam site is 322 square miles.[b]

Precise data regarding the flow of the river in 1908 are not available, but the general conditions may be summarized: Maximum-flow periods occurred in January and February, after which the discharge decreased and the bed of the stream at the ranch was quite dry until early in December. During December rainfall in the Santa Lucia Mountains brought a renewal of surface flow, and the river remained as a surface-flowing stream for the remainder of the year.

The results of the investigation are presented in the accompanying analyses:

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[a] Office records of U. S. Geol. Survey.

[b] Hamlin, Homer, The water resources of Salinas Valley, California: Water-Supply Paper U. S. Geol. Survey No. 89, 1904, p. 91.

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Mineral analyses of water from San Antonio River near Bradley.

[Parts per million unless otherwise stated.]

Date.		Turbidity.	Suspended matter.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.
From—	To—													
1907. Dec. 31	1908. Jan. 9	5	.....	32	0.9	56	15	21	0.0	171	85	1.5	14	314
1908.														
Jan. 10	Jan. 19	5	.....	32	.04	64	16	25	.0	181	81	1.4	15	316
Jan. 20	Jan. 29	122	76	31	.03	50	13	20	.0	149	52	1.2	11	260
Jan. 30	Feb. 8	50	68	32	.08	45	11	27	.0	146	60	.34	9.2	242
Feb. 9	Feb. 18	120	197	31	.25	46	13	25	.0	153	61	1.7	9.8	245
Feb. 19	Feb. 28	8	.....	37	.14	52	17	24	6.0	157	70	.70	12	280
Feb. 29	Mar. 9	10	.....	28	.05	42	12	19	6.0	154	62	.74	11	253
Mar. 10	Mar. 19	5	.....	32	.18	47	15	25	.0	173	69	1.2	11	278
Mar. 20	Mar. 29	Trace.	.....	34	.03	48	16	22	12.0	156	77	.78	11	291
Mar. 30	Apr. 8	5	.....	30	.48	51	17	23	7.2	168	80	1.1	13	295
Apr. 9	Apr. 18	5	.....	35	.06	54	16	26	.0	189	86	2.0	17	321
Apr. 19	Apr. 28	Trace.	.....	53	.09	53	17	24	7.2	166	82	1.2	14	327
Apr. 29	May 8	Trace.	.....	30	.19	53	20	23	8.4	162	82	1.9	14	310
May 9	May 18	5	.....	34	.05	53	18	24	.0	185	85	2.0	15	318
May 19	May 28	Trace.	.....	36	.12	57	18	24	3.6	184	88	1.7	17	336
May 29	June 7	Trace.	.....	36	.18	67	21	21	2.4	214	108	.7	24	401
June 8	June 17	Trace.	.....	41	.19	75	24	44	2.4	249	131	1.1	32	476
June 18	June 27	Trace.	.....	41	.13	88	30	58	Tr.	298	161	.80	43	562
June 28	July 7	10	.....	41	.15	120	39	87	.0	368	226	.68	63	746
July 8	July 17	Trace.	.....	39	.21	108	35	78	17.	320	195	1.6	56	691
July 18	July 27	5	.....	55	.03	103	36	70	1.2	356	180	1.0	54	683
July 28	Aug. 6	Trace.	.....	47	.18	55	19	32	.0	246	58	1.2	19	352
Aug. 7	Aug. 16	Trace.	.....	40	.18	55	18	38	.0	238	58	2.0	19	335
Aug. 17	Aug. 26	Trace.	.....	43	.29	54	18	33	.0	242	60	1.4	19	334
Aug. 27	Sept. 5	Trace.	.....	43	.15	54	17	33	3.6	232	59	1.0	29	336
Sept. 6	Sept. 15	9	.....	43	.42	55	18	35	7.2	231	55	1.3	20	339
Sept. 16	Sept. 25	8	.....	24	.05	53	17	37	.0	242	54	1.3	21	338
Sept. 26	Oct. 5	Trace.	.....	36	.13	55	19	29	8.4	231	56	.1	20	344
Oct. 6	Oct. 15	5	.....	37	.06	54	20	43	.0	257	52	1.3	21	333
Oct. 16	Oct. 25	Trace.	.....	38	.18	53	19	41	.0	267	55	.62	21	349
Oct. 26	Nov. 4	Trace.	.....	35	.03	81	32	76	.0	261	154	1.1	48	575
Nov. 5	Nov. 14	Trace.	.....	35	.05	82	30	60	.0	311	142	.8	41	550
Nov. 15	Nov. 24	Trace.	.....	35	.05	77	35	63	.0	297	137	0	37	502
Nov. 25	Dec. 4	Trace.	.....	41	.08	74	28	52	.0	288	117	.24	31	477
Dec. 5	Dec. 14	Trace.	.....	33	.06	66	23	43	.0	220	107	.50	26	394
Dec. 15	Dec. 24	Trace.	.....	52	.08	62	22	42	.0	222	103	.34	25	392
Dec. 25	Dec. 31	Trace.	.....	33	.28	66	20	43	.0	222	106	.30	27	406
Mean		10	.....	37	.16	63	21	38	2.5	224	94	1.0	24	387
Percent of anhydrous residue		.....	.....	9.5	0.0	16.1	5.4	9.7	28.9	.....	24.0	0.3	6.1	.....

After the last heavy rains in February the amount of mineral matter in solution increased steadily until the end of May. Throughout the month of June this increase was greatly accelerated, the amount of dissolved matter rising from 336 parts to 746 parts per million within the month. After remaining at almost 700 parts per million for nearly a month there was a sudden drop, as the river became dry, to about 335 parts per million. This value was maintained with great constancy until the latter part of October, when there was another quick rise to 575 parts per million, followed by a steady falling off until the end of the year. Although all elements in solution increased during these two periods of great increase in dissolved materials, the largest increase was in the alkalies, sulphates, and chlorides. In each of these there was a percentage increase, while all other elements showed corresponding percentage decreases.

This curious phenomenon probably results from the evaporation of the water flowing just on or near the surface, which causes a much greater concentration of salts at the periods when surface flow is either just ceasing or just recommencing. Aiding the effect of renewed flow is the re-solution of leached salts as the subsurface stream rises in its bed and as the land is washed off later by the early rains. The extreme rise in total dissolved material shown during the first period is accounted for by the fact that the dry season was then well under way and the surface flow was very small—a mere ribbon of water flowing over the loose, sandy bed, from all parts of which evaporation was progressing. During the later period there was no surface flow to be evaporated and the water was rising in a dry sand bed into which it trickled slowly. Hence the absence of evaporation would be partly offset by the increased solution of salts remaining as leachings in the sand.

Suspended matter attained its maximum value during late January and early February, the largest average being 197 parts per million for February 9 to 18, inclusive. At no other time during the year was the water turbid. Corresponding to the period of turbidity is a period of low total dissolved solids, showing clearly the result of flood conditions.

The predominating basic element in this water is calcium, which averages nearly 16 per cent of the total dissolved matter. The variation of this element is entirely in accord with the variation in total mineral matter, the maximum quantity being 120 parts per million June 28 to July 7, and the minimum 42 parts per million February 29 to March 9. Sulphates are high, the analyses showing the marked tendency toward the predominance of the sulphate radicle in the water. In periods of drought the sulphate radicle replaces the bicarbonate radicle as the dominating acid of the water, one analysis showing a value of 226 parts per million.

This stream affords a striking example of the practically universal result of arid conditions. In regions of abundant rainfall vegetation is profuse and its decay produces considerable carbonic acid. The carbonic acid, combining with various elements to form soluble carbonates, is carried out in the soil waters as the carbonate radicle. Hence in the run-off from such regions the predominating acid will usually be carbonic acid. In arid countries, on the other hand, vegetation is deficient, carbonic acid is not produced in great abundance, and the predominating acid will be determined by the character of the mineral formations over which the water has flowed. In San Antonio River both of these processes operate, and in addition the effect of organic carbonic acid is to a certain extent masked by the presence of large amounts of mineral carbonates in the drainage area. In times of rainfall most of the water is derived from vegetated regions, in which the soil covering is sufficient to protect the underlying rock, and the water flowing off is impregnated with carbonic acid.

In the dry season this vegetation becomes dry and burnt. The soil is thus bared to the sun's action, and the water, flowing now from the greater depths only, loses its characteristic charge of carbonic acid and assumes a character depending upon the soluble minerals of the subsoil stratum—in this area largely sulphates and carbonates.

Chlorides are high—higher, possibly, than proximity to the coast alone would cause. The normal flood-discharge value of this radicle appears to be about 10 parts per million, but it reached as high as 63 parts per million during June, 1908, and its dry-weather value is unfailingly high.

The water of San Antonio River can be used at all times for irrigation—a use that would necessitate storage and thus reduce the content of dissolved minerals below the average shown. The water is hard, will form scale readily, will cause large consumption of soap, and in general is one which must be softened if used for industrial purposes. For drinking it should be boiled or filtered. The addition of a small amount of soda ash would tend to prevent the formation of scale on kitchen utensils.

The river is one of the most easily available and accessible sources of supply of water for irrigation in Salinas Valley. Crops would be exposed to little danger from black alkali in the river water. In flood seasons practically no normal carbonates are present, and when they are present the amount of water flowing is relatively small.

NACIMIENTO RIVER.

DESCRIPTION.

Nacimiento River rises in the Santa Lucia Mountains near the headwaters of San Antonio River, and flows parallel to the latter throughout its course. Its upper valley is narrow, with a decided slope, while the lower valley consists of broad, rolling mesa lands, through which the river winds in a wide, sandy bottom. Throughout most of the lower part of its course the river is dry in summer, flowing above ground only in short stretches. Practically the whole of the lower river is within the boundaries of the Nacimiento ranch, and its valley is devoted entirely to cattle grazing. The total drainage area of the river is about 380 square miles.[a]

The stream is torrential in character, the banks on either side being constantly worn away by the winter floods, and as a result the river bottom has in many places been widened to extend as much as 400 feet from bank to bank. There are practically no sites on this stream suitable for erecting dams for storage reservoirs, especially in the lower valley.

The discharge of the Nacimiento is of the same character as that of the San Antonio. Exact measurements for 1908 are lacking, but records for 1901[a] show that the flow is about the same in the two streams, Nacimiento River carrying slightly more water than the San Antonio.

[a] Office records, U. S. Geol. Survey.

[b] Water-Supply Paper U. S. Geol. Survey No. 89, pp. 50–51; and No. 66, p. 154.

CHARACTER OF WATER.

Samples of the water were collected during 1908 by agents of A. F. Benton, of the Nacimiento ranch, at a point about 500 feet above the ranch house. The river here normally flows above ground all the year, but during the summer of 1908 it was dry for some months and a hole had to be dug in the sand bed to allow the cattle to water. Another smaller hole was used for a sampling station. The drainage area of the river at the sampling point is about 300 square miles.[a]

During 1908 there were two periods of turbid water. The first, in January and February, was due to the late seasonal rains of the winter; the second, in October, November, and December, resulted from the thunderstorms of the fall and the early rains of the new wet season. During the greater part of the summer the river was dry, and a decided increase was noted in the amount of dissolved mineral matter in the samples. The records show no fluctuation in the amount of dissolved material corresponding to the midseason drop in San Antonio River.

Calcium is the principal basic constituent of the water, sodium and potassium together rank second, and magnesium approaches very closely to and at times even exceeds the alkalies. The bicarbonate is the principal acid radicle, sulphates are second in importance, and chlorides are generally third, while the nitrates play a varying part, reaching a maximum of 40 parts per million in one set of samples.

The seasonal variation in dissolved matter is normal. The minimum quantity of dissolved material was found in January, when 178 parts per million were recorded. Maximum dissolved solids occurred August 17 to 26, inclusive, the analysis of the composite sample showing 403 parts per million. In general the dissolved salts appear to be less in the Nacimiento than in the San Antonio, except in the midsummer season, when the abnormal drop in the dissolved material in the San Antonio occurred.

The remarkable fluctuation in nitrates in the Nacimiento is easily accounted for by the fact that the whole middle valley is given over to cattle raising, the river being used as a watering place by between three thousand and four thousand head of cattle. The result is that in the dry season, when the stream flow is small and when the cattle frequent the river in greater numbers, large amounts of organic waste are deposited in the stream, charging the water very highly with chlorine and organic material. Decomposition of the latter gives rise to excessive nitrates and ammonia. Some of the samples collected in the dry season gave off a very strong animal odor and even showed at times a high color from the organic salts.

The water is excellent for irrigation, and if a storage reservoir could be located within reasonable distance of the Salinas Valley the water could be utilized to render large areas of the valley productive.

[a] Planimeter measurement on United States Land Office map.

But there appear to be no good sites in the lower valley, none, at least, nearer than the Santa Lucia foothills. Neither in this river nor the San Antonio is serious danger to be apprehended from silting up of storage reservoirs or canals. So long as the mountain reaches are wooded and so long as the basin is not further bared of protective vegetation little suspended material will be brought down in floods.

If well filtered the water would make a good domestic supply provided the cattle were prevented from wading above the point of intake. Its hardness is largely permanent, and the addition of soda ash would be advisable to render it suitable for use in steam boilers. The high nitrates in the water at times might, however, cause corrosion. Both this river and the San Antonio vary so greatly in discharge that all general statements must be qualified by the assertion that the value of the water depends upon the amount of the stream flow at the time of use.

Mineral analyses of water from Nacimiento River near San Miguel.

[Parts per million unless otherwise stated.]

Date.		Turbidity.	Suspended matter.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.
From—	To—													
1908.	1908.													
Jan. 10	Jan. 19	5	.....	25	0.10	38	19	16	0.0	157	55	0.56	10	238
Jan. 20	Jan. 29	45	58	22	.25	30	16	18	.0	131	49	.52	7.5	194
Jan. 30	Feb. 8	50	54	23	.18	30	13	12	.0	127	42	1.4	6.5	178
Feb. 9	Feb. 18	10	.....	24	.18	36	17	16	.0	159	63	2.0	10	235
Feb. 19	Feb. 28	5	.....	22	.15	35	18	16	.0	159	53	.44	8.5	220
Feb. 29	Mar. 9	4	.....	27	.23	36	19	16	6.0	153	66	.56	9.1	249
Mar. 20	Mar. 29	Tr.	.....	20	.14	45	21	23	.0	173	73	1.6	12	266
Mar. 30	Apr. 8	5	.....	25	.18	39	19	20	.0	174	68	2.2	10	257
Apr. 10	Apr. 19	5	.....	21	.35	42	22	26	2.4	173	75	2.2	11	278
Apr. 29	May 8	Tr.	.....	19	.28	45	22	19	9.6	151	79	1.7	13	274
May 9	May 18	Tr.	.....	14	.26	42	22	20	11	149	70	1.4	12	268
May 19	May 28	Tr.	.....	17	.18	36	21	20	2.4	144	75	1.5	13	258
May 29	June 7	Tr.	.....	20	.12	34	21	21	9.8	122	70	1.8	15	244
June 8	June 17	Tr.	.....	26	.18	34	21	24	8.4	122	72	.20	14	251
June 18	June 27	Tr.	.....	28	.21	40	21	22	3.6	148	73	2.0	15	278
June 28	July 7	5	.....	30	.15	42	20	20	.0	168	74	2.0	16	300
July 8	July 17	*a* 50	42	29	.15	52	26	28	.0	222	66	4.0	19	340
July 18	July 27	Tr.	.....	33	.11	45	24	33	.0	290	54	2.5	23	376
July 28	Aug. 6	*a* 325	734	34	.25	46	25	30	.0	244	69	2.0	20	380
Aug. 7	Aug. 16	*a* 150	1,000	35	.15	58	29	27	.0	218	95	40	18	383
Aug. 17	Aug. 26	.....	.....	43	.38	60	26	83	.0	199	102	8.0	17	403
Aug. 27	Sept. 5	Tr.	.....	16	.39	53	25	29	.0	195	97	20	16	361
Sept. 6	Sept. 15	*a* 9	.....	28	.21	44	22	23	.0	185	72	3.2	13	295
Sept. 16	Sept. 25	*a* 60	97	27	.02	42	20	21	.0	171	77	2.5	14	285
Sept. 26	Oct. 5	.....	.....	27	.09	42	23	21	.0	162	80	14	15	304
Oct. 6	Oct. 15	Tr.	.....	20	.03	35	17	22	.0	159	64	7.7	10	227
Oct. 16	Oct. 25	20	19	25	.53	41	21	21	.0	156	81	6.5	14	301
Oct. 26	Nov. 4	8	.....	25	.24	39	21	30	.0	154	73	2.1	15	278
Nov. 5	Nov. 14	25	57	30	.12	37	21	28	.0	156	68	1.2	15	265
Nov. 15	Nov. 24	55	72	26	.12	39	21	25	.0	151	72	3.6	13	274
Nov. 25	Dec. 4	8	.....	27	.18	44	24	28	.0	176	81	4.0	18	313
Dec. 5	Dec. 14	12	39	24	.06	44	25	33	.0	193	79	4.0	18	314
Dec. 15	Dec. 24	Tr.	.....	20	.16	46	26	32	.0	198	82	1.2	20	327
Dec. 25	Dec. 31	Tr.	.....	21	.12	43	27	34	4.8	173	83	.32	22	310
Mean		36	.....	25	.19	42	22	24	1.7	171	72	4.4	14	286
Per cent of anhydrous residue		.....	.....	8.6	0.1	14.5	7.6	8.3	29.8	.....	24.8	1.5	4.8	.....

a Turbidity due to cattle agitating pool from which samples were taken. High NO_3 due to cattle pollution.

SAN BENITO RIVER.

DESCRIPTION.

San Benito River drains that portion of the Coast Range lying south of Monterey Bay and east of the Salinas Valley—in all about 220 square miles. The river rises near San Benito and Lookout mountains, flows northwestward for about 60 miles, and joins Pajaro River in the vicinity of Sargents, whence it continues its course westward as the Pajaro and enters Monterey Bay a short distance south of Santa Cruz. The upper portion of the basin is rough and broken and the formation is of granite overlain with shales and sandstones. The bed of the valley is wide and flat and is composed of deep beds of sand into which the waters of the river disappear during the dry season.

The principal industry of this region is agriculture, although some stock raising is carried on in the hills. The waters of the San Benito are diverted into irrigation ditches a short distance above Hollister and used in the lower valley. Quantities of peaches, plums, and apricots are raised. Farther north, where the conformation of the bed rock again brings the ground waters nearer the surface and where Pajaro River cuts through the Coast Range, is the Pajaro Valley, the principal apple-raising district of the State.

The flow of the stream is torrential because precipitation on the watershed is altogether in the form of rain. Greatest discharge takes place during the late winter and early spring. No discharge measurements of the river are available.

CHARACTER OF WATER.

Samples of water for this investigation were collected at the headworks of the irrigation ditch a short distance above Hollister and forwarded to the laboratory through the courtesy of Mr. N. C. Briggs. The results of the study are shown in the accompanying analyses.

At times of flood discharge the river carries large quantities of suspended matter, mostly in the form of coarse sand. Later in the season the water becomes clear again, and still later the entire flow of the stream disappears in the deep beds of sand which fill its channel.

Owing to the amounts of magnesium contained in the rocks of this region the waters show on analysis quantities of magnesium proportionately much greater than in almost any other river in the State. As large amounts of sulphates are also present, it is evident that the water should not be used in steam boilers unless some adequate means of softening are adopted. It is, however, fit for irrigation, as experience in the valley has shown. For municipal

supplies it can not be recommended. That the water in the smaller creeks at the higher levels is much superior is shown by the result of an analysis of the water of Pescadero Creek, the sample being collected at Grass Valley March 31, 1908, and an analysis of water from the San Benito at Hollister, the sample being taken on the same day. Pescadero Creek is the source from which the municipal supply of the city of Hollister is derived.

Mineral analyses of water from San Benito River at Hollister.

[Parts per million unless otherwise stated.]

Date.		Suspended matter.	Silica (SiO_2).	$Fe_2O_3+Al_2O_3$.	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Total solids.
From—	To—												
1906.	1906.												
Jan. 1	Jan. 10	176	25	1.4	65	92	234	2.0	27	356	383	184	1,136
Jan. 11	Jan. 20	4,448	26	1.4	58	35	80	4.7	0.0	229	140	68	516
Jan. 21	Jan. 30	1,224	25	3.2	92	.....	126	5.4	0.0	375	246	118	856
Jan. 31	Feb. 9	94	15	3.4	62	59	165	5.4	6.5	384	270	147	950
Feb. 10	Feb. 19	934	16	1.6	52	60	119	2.4	16	363	208	99	728
Feb. 20	Mar. 1	2,376	27	3.0	38	36	44	3.0	0.0	.....	109	.....	502
Mar. 2	Mar. 11	3,650	25	3.4	54	40	58	2.4	0.0	273	144	60	522
Mar. 12	Mar. 21	5,808	24	4.0	35	27	36	.....	4.9	191	80	32	356
Apr. 1	Apr. 9	1,518	26	2.0	49	39	42	5.4	0.0	271	88	40	508
Apr. 11	Apr. 17	132	23	3.8	47	53	67	3.3	5.0	322	130	59	576
May 13	May 20	100	26	4.0	64	58	110	5.3	2.7	331	197	96	718
May 21	May 30	2,530	28	3.0	57	62	105	3.8	8.8	318	217	98	776
May 31	June 10	92	24	3.8	53	70	91	1.8	11	362	187	76	740
June 11	June 20	34	26	5.8	53	67	90	3.6	0.0	359	235	106	824
June 21	June 30	172	24	6.6	62	72	123	5.1	3.0	362	272	130	936
				Fe.									
Dec. 1	Dec. 10	112	32	.10	68	80	180		8.0	456	310	141	1,000
Dec. 11	Dec. 20	1,104	21	.10	84	56	122		6.0	375	212	74	706
Dec. 21	Dec. 30	1,498	20	.07	57	66	144		12	372	254	93	836
Mean		1,444	24	[a].09	58	57	110		6.2	335	204	95	732
Percent of anhydrous residue		.....	3.3	0.0	8.1	8.0	15.3		23.8	.....	28.3	13.2	.....

[a] Mean of Fe values after December 1.

Analyses of water of Pescadero Creek at Grass Valley and San Benito River near Hollister.

[Analyst, Walton Van Winkle. Quantities in parts per million.]

	Pescadero Creek.	San Benito River.		Pescadero Creek.	San Benito River.
Silica (SiO_2)	28	17	Bicarbonate radicle (HCO_3)	107	425
Iron (Fe)	.08	.17	Sulphate radicle (SO_4)	13	214
Calcium (Ca)	30	50	Chlorine (Cl)	19	69
Magnesium (Mg)	7.6	78	Total solids	166	756
Sodium and potassium (Na+K)	21	107	Turbidity	Trace.	50
Carbonate radicle (CO_3)	0.0	7.2	Suspended matter	.....	78

CARMEL RIVER.

DESCRIPTION.

Carmel River rises on the coastal side of the Santa Lucia Range, flows in a generally northwest direction, and empties into Carmel Bay. Throughout its course it traverses a narrow, heavily timbered valley, which widens out near the coast into a broad, fertile plain edged by the Santa Lucia and Sierra de Salinas ranges. The total drainage area of the river is 275 square miles.[a] The formations exposed are chiefly granitic rocks with some sedimentary sandstones and shales.

CHARACTER OF WATER.

Two samples were taken from this river in 1908 about 2 miles above Carmel by the Sea, one on April 10 and one on August 29. The results of the analyses of these samples are shown in the following table:

Analyses of water of Carmel River, 2 miles above mouth.

[Collector and analyst, Walton Van Winkle. Quantities in parts per million.]

	April 10, 1908.	August 29, 1908.		April 10, 1908.	August 29, 1908.
Turbidity	5	Trace.	Carbonate radicle (CO_3)	0.0	7.2
Silica (SiO_2)	24	27	Bicarbonate radicle (HCO_3)	134	151
Iron (Fe)	.45	.14	Sulphate radicle (SO_4)	56	79
Calcium (Ca)	38	50	Chlorine (Cl)	25	47
Magnesium (Mg)	12	18	Nitrate (NO_3)	.36	.8
Sodium and potassium (Na+K)	33	43	Total solids	248	336

Being a typical coastal stream, Carmel River may be expected to carry large quantities of sodium and chlorine. The value for sodium is only slightly less than that obtained for calcium, while chlorine was present in the first sample analyzed to the amount of 25 parts per million, or 10 per cent, and in the second to the amount of 47 parts per million, or 14 per cent. The carbonates are low, in the second sample yielding place to the sulphates as the predominating constituent.

The water is suitable for irrigation and, if filtered, for domestic use, although it is hard. For use in boilers it should be treated with soda ash to remove permanent hardness and prevent the obnoxious sulphate scale. It can not be used without treatment for industrial purposes where water plays a chemical part. However, as a municipal supply it is fairly satisfactory, and the cities of Monterey and Pacific Grove so use it at present, the intake of the water supply being above the limit of habitations in the valley.

[a] Hamlin, Homer, the water resources of Salinas Valley, California: Water-Supply Paper U. S. Geol. Survey No. 89, 1904, p. 77.

SANTA MARIA RIVER.

DESCRIPTION.

Santa Maria River drains that portion of the Coast Range lying between the San Rafael Mountains and the southernmost end of the Diablo Range. It flows westward and discharges into the Pacific Ocean at Guadalupe, about 25 miles south of San Luis Obispo. It is torrential in character—subject to floods of short duration during the rainy season, but being practically dry during the summer months. It receives numerous tributaries, the most important of which is the Sisquoc, which joins it about 12 miles above Santa Maria.

The country throughout this basin consists of rolling foothills, except the higher elevations of the San Rafael Mountains, which reach altitudes of 6,000 to 8,000 feet above sea level. The river breaks from the foothills at the point where it is joined by the Sisquoc and flows through a flat for a distance of 25 miles until it reaches the ocean.

The bed rock is shale, sandstone, or conglomerate, with a good covering of clay soil. Considerable timber is found on the higher elevations, but over most of the region timber is scanty, large areas being covered with brush and grass. A large part of the basin, especially in the higher regions, is given up to pasturage. Lower in the valley agriculture is the principal industry. The water for the irrigation of these areas is derived chiefly from wells driven in the valley floor. No diversions are made from the river for this purpose. Precipitation in this basin is almost entirely in the form of rain, the small amount of snow that falls on the higher portions of the watershed being insufficient to maintain a constant flow in the stream during the dry season.

CHARACTER OF WATER.

Samples of water for this investigation were collected at the gaging station near the house on Dutard's ranch, about 25 miles above Santa Maria.[a] The stream at this point is swift at all stages; its bed is composed of sand and gravel, part of which is overgrown with brush, and its banks are high and rocky and not liable to overflow.

A large quantity of suspended matter is carried by the river during flood periods, when the water also carries its minimum quantity of dissolved mineral matter, and if the flood water could be stored it would form a fairly good supply for use in irrigation. During the dry season the flow is small and the mineral matter is high. Calcium, magnesium, and sodium are abundant, as well as sulphates, chlorides, carbonates, and bicarbonates.

[a] For data concerning gage heights and discharges, see Water-Supply Papers U. S. Geol. Survey Nos. 100, 134, and 177.

The water is unsuited for domestic or industrial use. The high content of magnesium and calcium, along with the sulphates, marks it as very bad for use in boilers. The tendency of the water to deposit black alkali at certain seasons shows it to be ill adapted for irrigation.

Mineral analyses of water from Santa Maria River at Santa Maria.

[Parts per million unless otherwise stated.]

Date.		Turbidity.	Suspended matter.	Silica (SiO_2).	$Fe_2O_3+Al_2O_3$.	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Total solids.
From—	To—													
1906.	1906.													
Jan. 2	Jan. 10	.....	6.0	22	5.6	342	164	247	6.1	0.0	228	1,617	127	.....
Jan. 11	Jan. 20	.....	74	24	1.8	287	149	278	8.3	.0	200	1,492	127	2,776
Jan. 21	Jan. 30	.....	1,030	68	5.0	314	164	.....	.....	.0	243	912	122	2,992
Jan. 31	Feb. 9	.....	7,744	20	8.6	462	162	351	12	.0	429	1,684	137	3,252
Feb. 10	Feb. 19	.....	1,998	18	6.6	406	152	170	6.7	.0	244	1,614	116	2,948
Feb. 20	Feb. 25	.....	1,028	30	7.2	322	142	230	6.3	.0	248	1,458	115	2,540
Mar. 1	Mar. 8	.....	190	20	2.8	346	162	181	7.2	.0	228	1,561	124	3,004
Mar. 18	Mar. 21	.....	5,520	19	8.4	253	69	86	4.5	.0	190	768	54	1,516
Mar. 22	Mar. 31	.....	2,002	18	4.6	190	60	78	4.5	[a]9.8	224	556	48	1,200
Apr. 1	Apr. 10	.....	456	20	3.2	206	82	83	3.5	.0	276	699	67	1,512
Apr. 11	Apr. 20	.....	334	22	2.8	279	113	159	8.5	.0	269	977	87	1,926
Apr. 21	Apr. 28	.....	Trace.	20	3.0	264	124	186	7.2	.0	264	1,122	103	2,274
May 4	May 9	.....	70	17	5.0	258	123	197	11.0	.0	253	1,110	100	2,152
May 10	May 20	.....	42	.....	5.6	273	134	181	5.6	.0	257	1,215	118	2,372
May 21	May 30	.....	146	22	6.6	270	121	116	4.7	.0	254	1,080	87	2,126
June 1	June 10	.....	46	26	7.0	272	131	163	5.4	.0	243	1,175	100	2,330
June 11	June 20	.....	20	27	7.4	274	145	134	8.2	.0	232	1,335	110	2,508
June 21	June 30	.....	Trace.	30	6.8	348	145	136	4.6	.0	222	1,287	110	2,480
					Fe.									
July 1	July 10	.....	.....	27	.10	233	125	226		[a]4.0	212	1,123	94	2,218
July 11	July 19	.....	38	20	.10	169	93	154		.0	301	734	84	1,564
July 20	July 31	.....	8,430	24	.20	312	158	207		.0	291	1,557	127	2,910
Aug. 1	Aug. 10	.....	414	30	.30	324	143	223		[a]4.0	242	1,370	103	2,624
Aug. 11	Aug. 20	.....	8	22	.10	321	146	192		.0	224	1,427	105	2,654
Aug. 21	Aug. 31	.....	Trace.	20	.20	359	143	225		.0	227	1,357	101	2,526
Sept. 1	Sept. 10	.....	50	17	.10	288	136	223		.0	219	1,261	00	2,386
Sept. 11	Sept. 20	.....	8.0	19	.20	258	122	159		[a]5.0	226	1,068	91	2,084
Sept. 21	Sept. 30	.....	Trace.	20	.20	231	106	197		.0	290	957	81	1,878
Oct. 1	Oct. 10	.....	Trace.	26	.05	203	93	191		.0	320	769	75	1,638
Oct. 11	Oct. 20	.....	36	24	.10	274	122	244		.0	293	1,083	97	2,178
Oct. 21	Oct. 31	.....	Trace.	22	.10	299	141	282		.0	264	1,381	121	2,592
Nov. 1	Nov. 10	5	Trace.	26	.30	334	158	102		[a]7.0	224	1,503	127	2,824
Nov. 11	Nov. 20	5	24	35	.15	330	160	290		.0	247	1,569	130	2,832
Nov. 21	Nov. 30	400	274	26	.10	374	169	300		.0	282	1,700	140	3,014
Dec. 1	Dec. 10	400	224	20	.02	335	154	.....		.0	243	1,461	130	2,974
Dec. 11	Dec. 20	4,000	5,600	18	.10	456	149	264		.0	278	1,648	131	2,946
Dec. 21	Dec. 31	>7,000	9,776	21	.02	406	128	229		.0	210	1,473	105	2,656
Mean		.....	1,302	24	[b].14	302	133	200		.0	254	1,253	105	2,412
Per cent of anhydrous residue		.....	.....	1.1	0.0	14.1	6.2	9.4		5.8	.....	58.5	4.9	.....

[a] Abnormal. Computed as HCO_3 in the average.

[b] Mean of Fe values after July 1.

SANTA YNEZ RIVER.

DESCRIPTION.

Santa Ynez River rises in the mountains of Santa Barbara and Ventura counties and flows westward with a flat grade to the Pacific Ocean, a distance of about 75 miles. The basin is bounded on the north by the San Rafael Mountains and on the south by the Santa Ynez, altitudes ranging from 3,000 to 4,000 feet above sea level. The northern part of the basin is drained by streams running southward and uniting with the Santa Ynez proper, which hugs the base of the Santa Ynez Mountains. The principal tributary, Mono Creek, enters from the north.

The bed rock throughout this basin is shale and sandstone. The greater part of the area is covered with brush and small trees; only on the higher elevations is there any considerable amount of timber. As precipitation on this drainage area is almost entirely in the form of rain, the stream discharge is torrential, the greatest flow occurring during the late winter and early spring.

CHARACTER OF WATER.

Samples for this investigation were collected at the north portal of the tunnel known as the Gibraltar dam site by N. Clark. The stream at this point is swift, between banks which are low but not likely to overflow. The bed is composed of sand and gravel.[a]

At flood periods the river carries large amounts of suspended matter, but the water becomes clear again after a short time. The dissolved mineral matter is high, and is of such character that the water must be classed as sulphated. Trouble may therefore be expected in the use of this water for steaming. The adoption of a lime and soda process for softening the water would lead to great economy in any industry using this supply. The water may be unhesitatingly adopted for household purposes if the drainage area is kept in a sanitary condition.

The river water is not at present used industrially, but works under construction will conduct it under the Santa Ynez Mountains to supply Santa Barbara and neighboring coast towns.

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[a] For data concerning gage heights and discharge, see Water-Supply Papers U. S. Geol. Survey Nos. 81, 100, 177, and 213.

A more detailed account of the water supply of Santa Barbara is contained in Water-Supply Paper No. 116.

Mineral analyses of water from Santa Ynez River at Santa Barbara.

[Parts per million unless otherwise stated.]

Date.		Turbidity.	Suspended matter.	Silica (SiO_2).	$Fe_2O_3+Al_2O_3$.	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Total solids.	Mean discharge.	
From—	To—														Acre feet per day.	Cubic feet per second.
1906.	1906.															
Jan. 1	Jan. 8	....	Trace.	27	1.0	80	39	45	2.6	0.0	309	224	26	686	7.58	3.8
Jan. 12	Jan. 20	....	446	23	2.0	90	40	21	3.2	.0	244	283	22	680	56.2	28.1
Jan. 21	Jan. 30	....	106	25	2.6	82	47	59	2.1	.0	289	334	27	806	30.8	15.4
Jan. 31	Feb. 9	....	42	29	2.6	87	48	63	2.3	.0	286	312	43	776	17.4	8.7
Feb. 10	Feb. 19	....	36	20	4.2	113	44	36	2.4	.0	255	317	33	758	111	56.1
Feb. 20	Feb. 28	....	36	21	3.6	116	49	37	3.9	.0	272	339	27	792	47.6	23.8
Mar. 2	Mar. 10	....	28	19	2.6	106	48	56	1.2	.0	233	309	26	754	69.2	35.1
Mar. 13	Mar. 20	....	692	18	3.6	104	40	32	3.1	.0	241	264	18	664	2,572	1,297
Mar. 31	Apr. 10	....	36	18	2.6	121	51	53	2.9	.0	270	326	18	800	597	301
Apr. 11	Apr. 20	....	18	24	3.2	111	53	36	2.2	.0	264	341	17	818	238	120
Apr. 21	Apr. 25	....	10	23	4.4	121	55	....	5.8	6.6	254	364	22	776	161	81.2
May 8	May 10	.....	.....	.....	.....	.....	.....	.....	.....	.0	273	.....	22	.....	83	42
May 11	May 20	....	Trace.	27	5.0	122	55	69	3.5	.0	276	360	22	838	64.8	32.9
May 21	May 31	....	42	26	6.0	109	45	45	2.2	.0	251	302	19	736	234	118
June 1	June 10	....	36	24	....	111	51	73	....	.0	256	331	22	782	73.2	37.1
June 11	June 20	....	.....	23	2.8	107	50	65	6.4	14	217	352	20	782	40	20.0
June 21	June 30	....	10	33	9.2	127	48	56	....	.0	217	330	24	730	28.8	14.5
					Fe.											
July 1	July 10	....	Trace.	22	.10	102	45	57		5.0	259	275	21	690	17.4	8.7
July 11	July 20	....	60	22	.05	95	44	59		12	235	275	28	690	10.2	5.8
July 21	July 30	....	12	30	.07	112	43	73		.0	264	263	21	654	6.40	3.2
Aug. 1	Aug. 10	....	12	29	.15	98	43	69		8.0	249	254	24	664	4.16	2.1
Aug. 11	Aug. 16	....	2	26	.20	103	43	70		8.5	232	258	24	696	2.78	1.4
Sept. 2	Sept. 10	....	2	28	.05	100	40	61		11	270	238	26	662	1.98	1
Sept. 11	Sept. 20	....	60	21	.05	88	44	72		5.5	273	254	24	646	1.98	1
Sept. 21	Sept. 30	....	24	23	.20	93	44	58		.0	290	251	27	670	1.98	1
Oct. 1	Oct. 10	5	48	29	.27	105	45	64		5.0	282	254	31	656	1.98	1
Oct. 11	Oct. 20	2	6	32	.10	86	51	67		.0	308	259	28	664	1.98	1
Oct. 21	Oct. 31	....	6	29	.10	92	41	74		5.5	304	290	28	664	1.98	1
Nov. 13	Nov. 20	2	6	25	.10	105	43	74		5.0	324	214	26	648	2.98	1.5
Nov. 21	Nov. 30	....	10	21	.07	74	43	51		.0	203	227	24	664	3.17	1.6
Dec. 3	Dec. 10	....	78	14	.15	61	40	51		.0	324	244	25	610	5.16	2.6
Dec. 11	Dec. 20	60	122	19	.02	114	42	62		.0	272	313	24	764	152	76.8
Dec. 21	Dec. 31	40	10	18	.05	105	35	58		.0	258	220	20	636	149	75.2
Mean		....	64	24	a. 11	101	45	58		2.6	265	287	25	714	145	73
Per cent of anhydrous residue		.....	.....	3.6	0.0	15.0	6.7	8.6		19.9	.....	42.6	3.6	.....	.....	.....

Date.		Turbidity.	Suspended matter.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.
From—	To—													
1907.	1908.													
Dec. 31	Jan. 9	5	.....	20	0.10	138	51	60	4.8	253	421	0.12	17	864
1908.														
Jan. 10	Jan. 19	5	.....	24	.08	64	57	132	4.8	268	419	.28	15	805
Jan. 20	Jan. 29	50	135	17	.15	136	45	49	4.8	244	336	Trace.	11	715
Jan. 30	Feb. 8	70	356	23	.18	99	47	54	0	264	357	1.1	15	794
Feb. 9	Feb. 18	60	64	29	.25	114	45	55	0	271	353	.33	12	769
Feb. 29	Mar. 9	Tr.	.....	19	.12	103	53	47	0	250	350	.90	11	764
Mean		32	.....	22	.15	109	49	66	2.4	258	373	.46	14	785
Per cent of anhydrous residue		.....	.....	2.9	0.0	14.3	6.4	8.6	16.9	.....	49.0	0.1	1.8	.....

a Mean of Fe values after July 1.

VENTURA RIVER.

DESCRIPTION.

The San Buena Ventura or, as it is commonly called, Ventura River, rises to the south of the Nordhoff Mountains and flows in a general southerly direction to the Pacific Ocean above Ventura. Its slope is steep and its valley is narrow in its lower course, while in its upper course it traverses Nordhoff Valley, a broad plateau devoted largely to the raising of oranges.

Just above the town of Ventura the Ventura County Power Company is building a dam to divert the waters of the river for municipal supply and for irrigation. The river at this point passes through a narrow canyon, the grade being high and the bed rocky. Bed rock is exposed on the northern side of the canyon and sinks away to the southward, but rises again nearly to the surface at the opposite bank. The bed of the canyon and its surface are covered with a good growth of brush and small trees.

CHARACTER OF WATER.

Samples of water were collected daily during 1908 at the dam site, through the kindness of Mr. J. E. Barker, and later of Mr. C. L. Frost, superintendent of the Ventura County Power Company. The company met all expenses for collection. No stream-flow records were kept during 1908 on this river. The results of the examination of the samples are shown in the accompanying analyses.

Mineral analyses of water from Ventura River near Ventura.

[Drainage area 210 square miles. Quantities in parts per million unless otherwise stated.]

Date. From—	Date. To—	Turbidity.	Suspended matter.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.
1907. Dec. 31	1908. Jan. 9	5	.....	23	0.09	132	29	49	2.4	222	268	0.56	22	620
1908. Jan. 10	Jan. 19	5	.....	25	.10	118	32	43	1.2	226	252	.46	23	619
Jan. 20	Jan. 29	40	8	21	.16	101	27	48	.0	199	225	1.1	17	546
Jan. 30	Feb. 8	35	56	20	.10	101	26	52	3.6	194	225	.32	9.9	522
Feb. 9	Feb. 18	20	5	24	.08	107	27	38	4.8	195	249	1.2	12	557
Feb. 19	Feb. 28	7	.....	24	.35	93	27	40	7.2	191	242	.50	13	563
Feb. 29	Mar. 9	Trace.	.....	22	.03	95	28	42	6.0	187	249	.64	14	568
Mar. 10	Mar. 19	Trace.	.....	21	.03	98	29	36	5.0	195	250	.84	16	563
Mar. 20	Mar. 29	Trace.	.....	22	.08	98	29	38	9.6	198	250	6.0	16	574
Mar. 30	Apr. 8	Trace.	.....	29	.04	100	30	40	12	193	252	1.8	16	596
Apr. 9	Apr. 18	Trace.	.....	25	.07	99	28	46	.0	211	254	.90	17	582
Apr. 19	Apr. 28	Trace.	.....	23	.05	101	28	43	9.6	198	259	.68	16	581
Apr. 29	May 8	Trace.	.....	14	.05	100	29	40	3.6	212	251	.75	19	600
May 9	May 18	Trace.	.....	18	.43	99	29	44	7.2	198	266	.46	18	600
May 19	May 28	Trace.	.....	21	.15	101	29	45	4.8	212	253	.34	21	598
May 29	June 7	Trace.	.....	23	.05	103	30	43	.0	223	252	.10	20	606
June 8	June 17	Trace.	.....	27	.30	109	28	44	Tr.	239	261	.68	19	628
June 18	June 27	Trace.	.....	11	.13	108	27	46	9.6	226	248	.70	20	595
June 28	July 7	Trace.	.....	23	.12	103	32	43	16	200	250	1.2	21	513
July 8	July 17	Trace.	.....	24	.08	101	30	42	4.8	221	252	.66	20	591
July 18	July 27	Trace.	.....	26	.08	103	30	47	4.8	223	247	1.2	20	606
July 28	Aug. 6	Trace.	.....	23	.18	106	31	44	7.2	230	251	.65	21	598
Aug. 7	Aug. 16	Trace.	.....	24	.23	108	30	40	.0	246	262	.50	22	610
Aug. 17	Aug. 26	Trace.	.....	28	.17	108	32	45	2.4	237	256	Tr.	22	632
Aug. 27	Sept. 5	Trace.	.....	23	.17	104	29	48	7.2	220	251	.10	20	611
Sept. 6	Sept. 15	Trace.	.....	24	.05	114	30	42	.0	255	255	.18	21	688
Sept. 16	Sept. 25	5	.....	23	.15	107	28	41	6.0	244	252	.20	21	622
Sept. 26	Oct. 5	5	.....	22	.12	107	30	45	.0	262	253	.50	22	639
Oct. 6	Oct. 15	5	.....	23	.12	105	31	45	2.4	254	249	.76	22	623
Oct. 16	Oct. 25	Trace.	.....	25	.04	105	30	65	.0	266	250	.24	23	637
Oct. 26	Nov. 4	Trace.	.....	23	.07	109	31	58	.0	262	253	.26	23	655
Nov. 5	Nov. 14	Trace.	.....	25	.15	108	31	61	.0	244	246	.....	23	631
Nov. 15	Nov. 24	Trace.	.....	28	.34	107	32	55	.0	249	252	.30	22	640
Nov. 25	Dec. 4	Trace.	.....	23	.05	111	32	56	.0	259	249	.20	25	637
Dec. 5	Dec. 14	Trace.	.....	24	.07	111	30	51	2.4	257	256	.64	24	635
Dec. 15	Dec. 24	Trace.	.....	25	.28	111	31	56	.0	257	249	.40	27	651
Dec. 25	Dec. 31	Trace.	.....	23	.35	112	35	74	4.8	259	263	.74	26	650
Mean.....		3	.....	23	.14	106	30	47	3.9	226	251	.72	20	605
Per cent of anhydrous residue..		.....	.....	3.9	0.0	17.9	5.1	7.9	19.4	.....	42.4	0.0	3.4	.....

The water of Ventura River, like that of other rivers of the coastal region of middle California, carries a large amount of dissolved solids. Prominent among the constituents appear calcium and sulphates, the latter averaging 42 per cent of the total dissolved material. Alkalies are high, as is also carbonic acid in the bicarbonate form. Chlorine is not exceptionally high nor is magnesium, the ratio of magnesium to calcium being 1 to 3½.

The samples showed little variation in the mineral content of the water between flood season and time of drought. Minimum values occurred in 1908 in early February, 522 parts per million being recorded for the composite sample of January 30 to February 8, inclusive; while the maximum, 688 parts per million, occurred in the middle of September. Turbidity is invariably low, the soil covering

of the area affording good protection from erosion and the rocky river bottom giving little chance for the gathering of silt from the bed of the stream.

The water is hard, is a poor supply for steaming, would need treatment to render it fit for use in boilers, and is to be classed among the less desirable supplies for municipal use. Although it is not bad for drinking, it is likely to produce unpleasant effects on persons not well accustomed to such highly charged waters. It should not be adopted for a municipal supply without purification.

MALIBU CREEK.

DESCRIPTION.

Malibu Creek, which enters the Pacific Ocean about 15 miles above the town of Santa Monica, is formed near the town of Calabasas by the union of Triunfo and Las Virgenes creeks. These creeks rise in the Santa Monica Mountains and flow southward to their confluence The drainage basin includes the northern part of the Santa Monica Range and the foothills immediately adjoining. The bed rock throughout the basin is of shale, sandstone, and conglomerate, with good soil covering. A sparse growth of timber is found on the higher elevations, but the greater part of the area is covered with brush and grass and is used for pasturage. Grain is raised on small areas. A reservoir has been constructed on the upper reaches of Triunfo Creek, and the water is used for irrigation during the dry months. The stream is very torrential in character, owing to the steep and barren nature of its drainage area and to the fact that the precipitation is wholly in the form of rain.

CHARACTER OF WATER.

Samples of water for this investigation were collected at the gaging station near Calabasas[a] by the gage reader. The stream at this point is swift and flows between high banks. The right bank is rocky. The bed of the river is composed of rock and gravel.

The creek carries large amounts of suspended matter during flood periods; at other times the water is fairly clear, but it then carries a high content of dissolved mineral matter. (See analyses.) Las Virgenes Creek, draining more of the sandstone area than Triunfo Creek, carries considerably more alkaline material. The discharge of Las Virgenes Creek is smaller than that of Triunfo Creek, and the water of Malibu Creek does not show the extreme alkalinity that might be expected.

[a] For data concerning gage heights and discharge, see Water-Supply Papers U. S. Geol. Survey Nos. 100, 134, 177, and 213.

The water would be classed as sulphate, because calcium and the sulphate radicle are both high. For this reason it is poorly adapted for industrial uses unless some means are taken to soften it. It is not unsuited for household use.

Mineral analyses of water from Malibu Creek near Calabasas.

[Parts per million unless otherwise stated.]

Date.		Turbidity.	Suspended matter.	Silica (SiO_2).	Fe_2O_3+Al_2O_3.	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Total solids.	Mean discharge.	
From—	To—														Acre-feet per day.	Cubic feet per second.
1906.	1906.															
Jan. 1	Jan. 10	....	32	33	3.0	160	78	104	4.1	0.0	344	566	66	1,266	1.59	0.8
Jan. 11	Jan. 20	....	50	42	2.0	143	70	98	.....	.0	327	499	58	1,140	1.86	.94
Jan. 21	Jan. 30	....	Tr.	37	3.8	110	61	69	2.0	.0	304	367	53	930	4.64	2.34
Jan. 31	Feb. 9	....	24	31	1.6	126	56	79	2.8	.0	289	331	69	842	1.82	.92
Feb. 10	Feb. 18	....	112	31	2.0	66	31	34	1.7	8.1	218	138	33	448	5.10	2.57
Feb. 19	Mar. 1	....	20	35	4.0	102	50	50	3.1	.0	287	256	42	680	4.50	2.27
Mar. 2	Mar. 11	....	2	33	5.2	105	57	60	1.3	3.3	277	359	58	966	5.99	3.02
Mar. 22	Mar. 31	....	310	25	4.4	43	26	35	2.7	.0	199	90	27	400	11.17	5.63
Apr. 1	Apr. 10	....	14	34	3.8	64	38	38	1.6	.0	251	159	28	536	73.4	37.
Apr. 11	Apr. 20	....	.....	30	.....	79	46	55	3.6	.0	256	172	27	576	37.3	18.8
Apr. 21	Apr. 30	....	26	36	5.0	82	48	53	4.7	.0	312	204	31	636	12.75	6.43
May 1	May 10	....	38	34	4.2	78	45	54	2.8	.0	272	200	35	604	19.8	10.0
May 11	May 20	....	12	32	3.8	83	46	61	5.4	.0	287	236	36	670	15.8	7.96
May 21	May 31	....	50	31	5.4	94	46	58	4.4	2.9	267	212	36	624	18.6	9.36
June 1	June 9	....	34	39	4.4	91	43	58	2.1	7.0	258	198	31	570	14.1	7.1
June 10	June 19	....	34	35	5.2	85	40	44	2.0	6.0	253	186	29	582	14.1	7.1
June 24	June 30	....	.....	31	3.6	73	43	59	3.8	11	247	187	30	592	14.1	7.1
					Fe.											
July 1	July 10	....	48	44	.20	78	42	53		8.0	257	217	30	578	10.9	5.49
July 11	July 20	....	30	34	.10	72	40	44		.0	273	181	30	594	8.73	4.40
July 21	July 30	....	4	40	.08	198	100	195		.0	378	830	81	1,766	8.73	4.40
Aug. 1	Aug. 9	....	44	48	.07	95	42	65		.0	283	188	31	598	8.73	4.40
Aug. 11	Aug. 20	....	4	42	.20	86	41	48		5.0	275	191	32	584	8.73	4.40
Aug. 21	Aug. 31	....	.....	34	.10	85	32	.....		.0	278	184	31	592	8.73	4.40
Sept. 1	Sept. 8	....	12	39	.20	89	42	34		9.0	261	186	30	596	8.73	4.40
Sept. 22	Sept. 30	....	26	41	.16	123	60	106		.0	324	399	50	976	5.02	2.53
Oct. 1	Oct. 10	....	4	39	.05	104	45	69		.0	322	238	41	708	8.73	4.40
Oct. 11	Oct. 20	....	30	37	.10	94	43	70		.0	319	198	36	614	8.73	4.40
Nov. 11	Nov. 20	5	60	43	.15	117	62	131		6.0	340	400	54	960	8.73	4.40
Nov. 21	Nov. 30	....	80	40	.15	138	70	111		.0	374	462	59	1,070	8.73	4.40
Dec. 1	Dec. 10	....	.....	30	.06	149	70	112		5.2	305	443	56	.....	9.26	4.67
Dec. 11	Dec. 20	15	102	30	.05	124	62	94		.0	345	410	61	932	11.0	5.54
Dec. 21	Dec. 29	400	498	31	.01	104	42	76		.0	245	233	40	656	7.62	38.4
Mean		....	61	36	[a].11	101	50	73		2.2	288	285	42	751	47	24
Per cent of anhydrous residue		....	.....	4.9	0.0	13.8	6.8	10.0		19.7	.....	39.0	5.8	.....	.....	.....

[a] Mean of Fe values after July 1.

VALLEY OF SOUTHERN CALIFORNIA.

DESCRIPTION.

The merging valleys of Los Angeles, San Gabriel, and Santa Ana rivers have been grouped together into what may be called the valley of southern California.[a] This valley lies south of the San Gabriel and San Bernardino mountains and west of the San Bernardino and San Jacinto mountains. On the south its limits are poorly defined,

[a] Mendenhall, W. C., Hydrology of San Bernardino Valley, California: Water-Supply Paper U. S. Geol. Survey No. 142, 1905, p. 9.

as it is there broken up into many smaller valleys by the irregular projecting ridges of the southern ranges. Much information has been gained concerning its waters by investigations made by the United States Geological Survey, and the literature on the subject is extensive.[a]

SAN GABRIEL RIVER.

DESCRIPTION.

San Gabriel River is formed on the southern slopes of the Sierra Madre by several small coequal streams, which unite just before the river enters its deep lower canyon, whence it emerges just above the town of Azusa into a broad alluvial valley, where it gradually sinks beneath the surface, its course being marked by a characteristic sand "wash."

At the lower end of the San Gabriel Valley, near Rivera, the seepage waters are brought to the surface again by an obstruction to the underflow and pass over the surface through a narrow gap in the surrounding hills in two distinct streams, one of which is called the San Gabriel and the other the Rio Hondo. Leaving the pass they again sink into the sandy soil of the valley below. The San Gabriel finally finds its way to San Pedro Bay, and the Rio Hondo joins Los Angeles River.

Above Azusa the San Gabriel Valley is rough and mountainous and the tributaries flow in deep, narrow canyons. The bed rock of these upper hills is granitic and the soil covering is fair. A heavy growth of timber is found in the foothills and a sparse growth above. Below Azusa the valley is broad and is covered with a deep soil of sand and alluvium. The bed of the river is gravelly and is interspersed with bowlders and sandy stretches.

The mountainous areas of the San Gabriel basin receive an annual rainfall of 20 to 40 inches. The greater part of this precipitation occurs during the winter, the months of June, July, and August being as a rule exceedingly dry. Ground storage facilities are, however, good, and there is continuous flow throughout the year.

Much of the water is diverted about 5 miles above Azusa for the power station of the Pacific Light and Power Company.

Samples of water were collected daily during 1908 near Azusa and at Rivera, and a single sample was taken from Rio Hondo near Rivera.

CHARACTER OF WATER NEAR AZUSA.

The samples of water for this investigation were taken from the diversion canal of the power company by J. P. Woodward, A. W. Peake, and J. W. Moon, of the company.

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[a] Water-Supply Papers U. S. Geol. Survey Nos. 81, 100, 134, 137, 138, 139, 142, 177, and 213.

According to measurements made at Azusa, 57 per cent of the total discharge of the stream during 1908 occurred between January 20 and April 18, the rise in gage height being very constant and the falling off rather gradual. Minimum summer flow was reached in the early part of September, the stream flowing from that time until the end of the year with slight fluctuation.

The analyses of the composite samples show no pronounced changes in the amount of total dissolved matter in the stream throughout the year. The period of maximum discharge was marked by a slight decrease in dissolved material, and the amount rose gradually from that time until the end of the year, but the total variation was only 56 parts per million.

Mineral analyses of water from San Gabriel River near Azusa.

[Drainage area, 222 square miles. Quantities in parts per million unless otherwise stated.]

Date.		Turbidity.	Suspended matter.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.	Mean discharge.		Run-off per square mile (cubic feet per second).
From—	To—														Acre-feet per day.	Cubic feet per second.	
1907. Dec. 31	1908. Jan. 9	Trace.	.....	24	0.20	60	12	19	2.4	190	40	0.40	3.7	240	103.5	52.2	0.2351
1908. Jan. 10	Jan. 19	Trace.	.....	21	.10	57	12	21	.0	196	41	.76	5.2	238	117.6	59.3	.2671
Jan. 20	Jan. 29	10	.....	21	.15	52	11	17	.0	161	33	1.2	5.1	204	493.3	248.7	1.1203
Jan. 30	Feb. 8	5	.....	22	.05	40	8.7	21	.0	160	27	.28	4.4	190	686.6	346.2	1.5595
Feb. 9	Feb. 18	Trace.	.....	25	.10	41	12	25	2.4	159	34	.48	3.5	196	487.9	246.0	1.1080
Feb. 19	Feb. 28	Trace.	.....	22	.12	44	12	14	6.0	164	29	.85	4.0	198	379.8	191.5	.8626
Feb. 29	Mar. 9	Trace.	.....	22	.08	44	11	16	.0	171	27	.38	4.0	195	377.6	190.4	.8552
Mar. 10	Mar. 19	5	.....	20	.05	42	11	19	3.6	167	27	.34	4.0	193	393.5	198.4	.8937
Mar. 20	Mar. 29	Trace.	.....	18	.03	41	11	11	2.4	161	29	.78	3.1	184	463.9	233.9	1.0536
Mar. 30	Apr. 8	Trace.	.....	19	.29	43	11	13	7.2	159	32	2.0	3.1	195	378.2	190.7	.8590
Apr. 9	Apr. 18	Trace.	.....	22	.04	44	10	13	.0	175	32	1.8	3.0	200	291.9	147.2	.6630
Apr. 19	Apr. 28	5	.....	19	.20	43	11	11	4.8	161	29	.40	4.0	191	279.6	141.0	.6351
Apr. 29	May 8	Trace.	.....	19	.05	42	12	9.9	13	143	29	1.0	2.6	187	314.7	158.7	.7149
May 9	May 18	Trace.	.....	20	.21	44	13	16	7.2	160	38	1.2	3.0	198	249.3	125.7	.5662
May 19	May 28	Trace.	.....	20	.08	46	12	12	7.2	163	36	1.0	2.5	192	182.9	92.2	.4153
May 29	June 7	Trace.	.....	18	.17	41	11	17	4.8	167	28	.75	4.0	201	161.1	81.2	.3658
June 8	June 17	Trace.	.....	18	.15	45	11	13	3.6	172	27	2.0	3.5	195	154.3	77.8	.3505
June 18	June 27	Trace.	.....	18	.08	44	11	13	4.8	172	29	.15	3.5	196	133.1	67.1	.3022
June 28	July 7	5	.....	21	.13	46	11	14	.0	171	42	1.1	3.7	211	92.2	46.5	.2095
July 8	July 17	5	.....	21	.23	46	13	14	7.2	171	31	.30	14.0	206	81.5	41.1	.1851
July 18	July 27	Trace.	.....	25	.15	43	13	18	1.2	178	29	1.3	6.0	212	73.4	37.0	.1666
July 28	Aug. 6	[a] 260	450	25	.50	44	14	15	1.2	179	32	.....	4.0	218	91.4	46.1	.2077
Aug. 7	Aug. 16	90	206	20	.32	43	11	25	3.6	171	32	.70	3.4	202	76.6	38.6	.1739
Aug. 17	Aug. 26	10	14	24	.35	47	14	15	7.2	166	39	.76	5.5	220	63.1	31.8	.1387
Aug. 27	Sept. 5	6	.....	18	.38	45	12	24	4.8	171	33	1.0	4.8	204	56.3	28.4	.1279
Sept. 6	Sept. 15	300	452	27	.50	40	13	13	.0	163	35	17.0	3.3	222	55.1	27.8	.1252
Sept. 16	Sept. 25	90	45	21	.18	42	13	17	6.0	168	32	Tr.	4.2	204	65.8	33.2	.1495
Sept. 26	Oct. 5	40	91	18	.10	39	13	23	11	166	30	.....	3.7	208	67.6	34.1	.1536
Oct. 6	Oct. 15	10	.....	21	.05	40	14	20	.0	196	35	Tr.	4.0	211	61.5	31.0	.1396
Oct. 16	Oct. 25	5	.....	17	.04	48	12	18	2.4	200	30	Tr.	3.0	213	73.0	36.8	.1657
Oct. 26	Nov. 4	Trace.	.....	19	.28	50	13	22	2.4	198	33	.28	5.0	228	63.7	32.1	.1446
Nov. 5	Nov. 14	Trace.	.....	18	.05	50	16	15	4.8	196	22	.12	4.5	221	64.1	32.3	.1455
Nov. 15	Nov. 24	Trace.	.....	19	.14	50	16	24	.0	201	24	.10	5.0	223	65.4	33.0	.1495
Nov. 25	Dec. 4	18	44	20	.08	47	14	27	.0	204	30	.20	3.7	223	92.4	46.6	.2099
Dec. 5	Dec. 14	4	.....	18	.08	49	14	20	.0	195	37	.50	5.5	220	102.1	51.5	.2319
Dec. 15	Dec. 24	Trace.	.....	21	.11	49	13	16	.0	205	34	.44	4.2	226	80.3	40.5	.1824
Dec. 25	Dec. 31	Trace.	.....	20	.08	50	14	29	.0	209	29	.28	4.7	239	78.1	39.4	.1775
Mean		23	.....	21	.16	45	12	18	3.3	176	32	1.1	4.3	208	190.5	96	.43
Per cent of anhydrous residue		.....	.....	9.4	0.1	20.1	5.4	8.0	40.3	....	14.3	0.5	1.9	....	.....	.....	.....

[a] Cloudburst July 31. Turbidities as follows: July 31, 775; August 1, 725; August 2, 380; August 3, 400; August 4, 340; August 5, 335. "River rose 4 to 6 feet July 31, 1908" (J. W. Moon).

The water is distinctly of the calcic-carbonate type. The amount of normal carbonates in this water is decidedly high, as is apparent from the table of analyses. Owing to the small amount of total dissolved solids present, however, the water can not be considered dangerous for use in irrigation.

The water requires little treatment to make it well adapted for steaming. Small amounts of soda ash added to it will precipitate the greater part of the calcium and magnesium present, and thus prevent the formation of hard scale in boilers. With proper protection from bacterial pollution the water would make an excellent municipal supply, the high nitrates found in it appearing to be due not so much to animal as to vegetal organic material.

CHARACTER OF WATER AT RIVERA.

Although only a small quantity of water is added to the San Gabriel by rainfall between Azusa and Rivera, the seepage waters which are brought above ground at Rivera by an obstruction to the underflow contain, besides the original San Gabriel River water, such water as is brought from either side for irrigation at the edges of the valley and such as may be pumped from the underground waters of the valley for irrigation. The total influx of these foreign waters must, however, be small, and the effect of the seepage between the towns of Azusa and Rivera must be demonstrated by the analyses of the samples taken at the two places. The Rivera samples were collected daily during 1908 by Mrs. S. E. Palett.

The changes that occur in the water of San Gabriel River between Azusa and Rivera are noteworthy as illustrating those taking place in a water flowing underground for a short distance, and the following table brings together for comparison the average results of analyses of water taken above and below the place of subsurface flow.

Comparison of the quality of water of San Gabriel River at Azusa and near Rivera, 1908.

	Mineralization, in parts, per million.		Percentage composition of anhydrous residue.	
	Azusa.	Rivera.	Azusa.	Rivera.
Silica (SiO_2)	21	23	9.4	8.8
Iron (Fe)	.16	.11	.1	.1
Calcium (Ca)	45	55	20.1	21.0
Magnesium (Mg)	12	12	5.4	4.6
Sodium and potassium (Na+K)	18	22	8.0	8.4
Carbonate radicle (CO_3)	3.3	2.2	40.3	40.6
Bicarbonate radicle (HCO_3)	176	211	.....	.....
Sulphate radicle (SO_4)	32	33	14.3	12.6
Chlorine (Cl)	4.3	8.4	1.9	3.2
Nitrate radicle (NO_3)	1.1	1.9	.5	.7
Total solids	208	246	.....	.....

There are increases in calcium, alkalies, bicarbonates, and chlorine. The average increase in bicarbonates is 35 parts per million, corresponding to 11.5 parts per million of calcium if all is the result of solution of calcium carbonate. The average increase in chlorine is 4.1 parts per million, corresponding to 2.7 parts per million of sodium as sodium chloride. The increase in carbonic acid may be expected, inasmuch as one of the results of the decay of plant life is the formation of carbonic acid, which in solution readily attacks calcium carbonate rocks and dissolves them. As the water is used extensively for irrigation and passes in its course through sandy and gravelly soil covered by a good vegetation, all conditions are favorable for such action, and undoubtedly that is what actually occurs. The increase in the amounts of these two elements is typical of the effect of more intimate contact with the materials of the river bed. The attendant rise in the quantity of nitrates present probably occurs from vegetable decay. In fact, the manner in which the charring occurred upon heating the evaporated salts from the water of the San Gabriel at Rivera leads to the conclusion that the greater proportion of organic material present is vegetable matter.

The water of the San Gabriel at Rivera shows a magnesium to calcium ratio of 1 to 4.6, or considerably lower than that found at Azusa. In other words, there is no introduction of magnesium corresponding to the increase in calcium in this water. Silica, also, shows a scarcely appreciable change, while the change in the sulphate radicle is practically nothing. The total effect of the subsurface passage of the water is an increase in mineralization without much change in the relative proportions of the substances present.

The similarity of the waters of San Gabriel River at Azusa and Rivera is such that little can be said regarding the value of one which is not equally true of the other. Of course, as the river at the lower point has received, in addition to any pollution reaching it above Azusa, large amounts of sewage of the valley, its use for domestic purposes would be extremely unsafe unless measures were taken to insure the removal of pathogenic bacteria.

Mineral analyses of water from San Gabriel River near Rivera.

[Parts per million unless otherwise stated.]

Date.		Turbidity.	Suspended matter.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.
From—	To—													
1907. Dec. 31	1908. Jan. 9	8	.....	25	0.15	68	11	17	0.0	218	40	15	6.9	262
1908.														
Jan. 10	Jan. 19	5	.....	24	.01	76	9.8	19	.0	217	34	.16	7.0	266
Jan. 20	Jan. 29	100	151	22	.11	63	8.5	19	.0	185	37	1.4	7.9	231
Jan. 30	Feb. 8	20	31	20	.07	50	9.8	19	.0	185	31	1.2	7.2	223
Feb. 9	Feb. 18	5	.....	22	.07	58	11	24	.0	200	38	1.1	5.0	236
Feb. 19	Feb. 28	5	.....	22	.08	60	11	24	.0	214	34	1.9	9.0	244
Feb. 29	Mar. 9	Trace.	.....	22	.05	58	13	21	2.4	207	33	1.8	7.4	241
Mar. 10	Mar. 19	5	.....	25	.05	52	10	23	7.2	203	28	2.1	7.5	249
Mar. 20	Mar. 29	Trace.	.....	30	.05	40	13	19	.0	213	26	3.0	7.9	237
Mar. 30	Apr. 8	5	.....	24	.05	52	12	20	.0	211	36	4.0	8.5	248
Apr. 9	Apr. 18	5	.....	25	.10	53	12	19	16	186	36	1.5	6.5	253
Apr. 19	Apr. 28	5	.....	24	.18	52	9.8	22	.0	215	35	2.0	6.5	247
Apr. 29	May 8	Trace.	.....	26	.03	54	13	18	.0	214	30	4.0	7.0	248
May 9	May 18	Trace.	.....	26	.10	54	12	19	4.8	209	29	.84	6.5	251
May 19	May 28	Trace.	.....	26	.18	57	12	22	.0	220	37	2.0	12	258
May 29	June 7	6	.....	22	.04	55	11	23	6.0	203	33	1.8	7.7	244
June 8	June 17	Trace.	.....	21	.08	54	12	18	.0	210	30	.56	8.9	238
June 18	June 27	Trace.	.....	21	.15	54	11	18	.0	221	36	.82	15	251
June 28	July 7	Trace.	.....	24	.08	53	11	18	9.6	193	29	1.6	8	240
July 8	July 17	Trace.	.....	23	.00	55	10	20	7.2	200	28	.86	7.7	237
July 18	July 27	Trace.	.....	19	.29	52	12	25	.0	212	30	1.2	7.5	243
July 28	Aug. 6	Trace.	.....	23	.16	53	12	19	.0	212	30	.....	8.5	240
Aug. 7	Aug. 16	3	.....	20	.04	54	12	23	6.0	207	30	.....	9.0	239
Aug. 17	Aug. 26	Trace.	.....	22	.19	55	12	20	7.2	203	29	1.4	8.0	245
Aug. 27	Sept. 5	3	.....	26	.12	62	13	26	9.6	201	32	1.6	17	268
Sept. 6	Sept. 15	Trace.	.....	33	.22	55	11	20	Tr.	222	29	1.2	7.5	255
Sept. 16	Sept. 25	Trace.	.....	20	.07	54	12	19	.0	224	29	1.3	8.5	246
Sept. 26	Oct. 5	Trace.	.....	23	.08	52	12	18	2.4	217	30	.....	7.5	230
Oct. 6	Oct. 15	5	.....	26	.07	55	12	23	.0	237	34	1.8	8.3	258
Oct. 16	Oct. 25	Trace.	.....	25	.13	53	11	38	.0	226	40	1.5	7.5	250
Oct. 26	Nov. 4	Trace.	.....	21	.12	54	11	20	2.4	221	30	1.2	9.5	248
Nov. 5	Nov. 14	6	.....	21	.08	52	11	20	.0	222	27	.98	8.0	246
Nov. 15	Nov. 24	Trace.	.....	21	.08	52	12	32	.0	217	30	.96	7.5	250
Nov. 25	Dec. 4	Trace.	.....	20	.15	50	13	24	.0	220	30	1.1	9.0	247
Dec. 5	Dec. 14	Trace.	.....	22	.34	42	12	37	.0	212	46	1.0	9.0	246
Dec. 15	Dec. 24	6	.....	25	.24	54	13	27	.0	220	38	.94	8.5	253
Dec. 25	Dec. 31	Trace.	.....	23	.04	53	16	35	.0	222	38	1.6	8.5	249
Mean		5	.....	23	.11	55	12	22	2.2	211	33	1.9	8.4	246
Percent of anhydrous residue		.....	.....	8.8	0.1	21.0	4.6	8.4	40.6	.....	12.6	0.7	3.2	.....

RIO HONDO.

DESCRIPTION.

Rio Hondo resembles the lower San Gabriel. Rising nearly at the same place in the narrows above Rivera, the rivers pass side by side through the gap in the hills but gradually draw farther apart, one merging with Los Angeles River and the other percolating underground to the Pacific Ocean.

CHARACTER OF WATER.

The following analysis of a sample of water collected from Rio Hondo near Rivera on March 16, 1906, shows the water to be essentially the same as that of the lower San Gabriel, and had daily samplings been made the average results would undoubtedly have been nearly identical.

Analysis of the water of Rio Hondo near Rivera, Cal., March 16, 1908.

[Sample collected and analyzed by Walton Van Winkle. Quantities in parts per million.]

Turbidity	Trace.	Carbonate radicle (CO_3)	2.4
Silica (SiO_2)	26	Bicarbonate radicle (HCO_3)	229
Iron (Fe)	.08	Sulphate radicle (SO_4)	21
Calcium (Ca)	50	Chlorine (Cl)	16
Magnesium (Mg)	13	Nitrate radicle (NO_3)	1.2
Sodium and potassium (Na+K)	26	Total solids	267

SANTA ANA RIVER.

DESCRIPTION.

Santa Ana River rises in the San Bernardino Mountains in the eastern part of the San Bernardino National Forest. Flowing westward in its upper course, the river emerges from the mountains through a deep precipitous gorge about 5 miles northeast of the town of Mentone, and traverses the broad San Bernardino Valley, sinking beneath its sandy bed and appearing on the surface only in flood seasons. Through this valley the river bottom is wide and shallow and the bed is composed of mixed sand and gravel. Near the city of San Bernardino the water rises to the surface and is here diverted for irrigation. Little of the river water appears again at the surface until it finally reaches the sea.

In its upper course the river passes through a rough, broken country, and receives many tributaries, chief among which is Bear Creek, the outlet of Bear Lake, on which a dam has been constructed to store the winter run-off for summer use. The bed rock of this part of the basin is granite and the soil covering is good.

The rich alluvial lands of the lower valley are devoted almost exclusively to the production of citrus fruits, the value of the river water for irrigation being great.

During 1908 samples of water were collected daily from the Santa Ana near Mentone and near Corona at the head of the canyon.

CHARACTER OF WATER NEAR MENTONE.

At Mentone the Pacific Light and Power Company has built a power station, to which much of the water of the river is diverted through a flume. The river bed at this point is composed of bowlders, with stretches of hard, firm sand; the current is swift, and the course of the stream is practically straight for a short distance. The samples were collected daily by Charles S. Putnam—from the flume during the period when all the water was diverted, but at other times from the river itself.[a]

The water of the upper Santa Ana is, like that of San Gabriel River, calcic carbonate in type. As stream flow is somewhat equalized by the effect of the storage of the headwaters, the mineral

[a] For data regarding gage heights and discharge of Santa Ana River, see Water-Supply Papers U. S. Geol. Survey Nos. 81, 100, 134, 177, and 213.

content shows no marked variation, the changes that occur being due apparently to local conditions apart from season or stream flow. The bicarbonate radicle is the predominating constituent, calcium and silica sharing the second place. Sulphates average over 12.5 per cent of the total dissolved material, while chlorides are unimportant. Turbidity is seldom great. The value for suspended solids exceeded 50 parts per million only twice in 1908, both times as the result of severe storms which were reported as cloudbursts. The water is well adapted for all purposes. For use in boilers small amounts of soda ash may be added to it to remove hard incrustants, but the chemical treatment of the water for ordinary industrial use is unnecessary. The water should be filtered or otherwise purified before it is used for domestic purposes.

Mineral analyses of water from Santa Ana River above Mentone.

[Parts per million unless otherwise stated.]

Date.		Turbidity.	Suspended matter.	Silica (SiO_2).	$Fe_2O_3+Al_2O_3$.	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Total solids.	Mean discharge including canal.		Mean discharge without canal.	
From—	To—														Acre-feet per day.	Cubic feet per second.	Acre-feet per day.	Cubic feet per second.
1906.	1906.																	
Jan. 1	Jan. 10	...	8	32	1.2	23	5.6	27	0.3	0.0	113	14	6.1	140	69.2	34.9	1.98	31.0
Jan. 11	Jan. 20	...	34	24	.8	31	4.4	16	2.4	.0	111	13	5.9	176	124	62.3	43.2	21.8
Jan. 21	Jan. 30	...	36	26	1.2	25	4.8	29	3.1	.0	119	16	6.9	132	88.3	44.5	11.5	5.8
Jan. 31	Feb. 9	...	42	26	1.8	37	10	14	1.8	.0	116	51	6.9	136	69.8	35.2	1.98	1.0
Feb. 11	Feb. 18	...	32	17	2.2	29	5.0	14	1.3	.0	112	9.9	11	156	113	57.0	1.98	1.0
Feb. 20	Feb. 28	...	8	21	2.8	25	4.8	18	1.2	.0	111	12	7.5	160	198	100	93.4	47.1
Mar. 2	Mar. 11	...	6	16	4.2	30	6.1	15	2.4	.0	117	15	8.8	156	124	62.4	25.8	13.0
Mar. 12	Mar. 19	...	808	13	2.4	19	4.1	9.1	1.5	.0	78	10	11	150	1,551	782	1,489	75.1
Mar. 23	Mar. 31	...	82	19	2.8	21	4.6	13	2.0	.0	82	7.4	6.9	160	1,926	971	1,846	93.1
Apr. 1	Apr. 10	...	4	18	4.0	33	7.2	16	3.8	.0	92	13	6.9	144	502	253	392	198
Apr. 11	Apr. 20	...	46	16	3.6	27	7.0	15	2.8	.0	96	15	5.9	124	384	194	246	124
Apr. 21	Apr. 30	...	16	14	4.4	24	6.8	13	2.4	.0	88	10	5.9	114	746	376	605	305
May 2	May 10	...	14	16	3.2	26	7.7	21	3.0	.0	94	10	6.2	138	530	267	388	196
May 11	May 20	...	24	16	1.8	20	5.2	12	1.1	.0	94	8.6	7.8	122	390	197	258	130
May 21	May 31	...	36	10	3.6	23	5.3	10	1.3	.0	90	11	5.9	128	544	274	423	213
June 1	June 10	...	32	16	3.4	23	5.7	12	2.0	.0	88	16	7.6	104	394	199	256	129
June 11	June 20	...	14	15	5.8	24	6.8	8.4	1.3	.0	89	12	5.9	142	329	166	190	95.8
June 21	June 30	...	...	...	...	...	...	...	...	...	...	...	...	...	297	150	159	80.2
					Fe.													
July 1	July 10	...	8	13	.10	21	6.7	14		.0	88	16	6.3	142	263	133	123	62.3
July 11	July 20	...	26	22	.05	19	4.7	15		a3.0	89	12	8.2	132	242	122	101	50.9
July 21	July 30	...	28	11	.08	28	5.0	14		.0	98	12	5.8	120	210	106	68.6	34.6
Aug. 5	Aug. 10	...	20	19	.07	32	5.8	22		.0	112	12	7.5	150	150	75.4	9.92	5.0
Aug. 12	Aug. 20	...	136	13	.17	33	5.3	18		.0	102	13	5.8	148	181	91.7	52.0	26.2
Aug. 21	Aug. 31	...	30	22	.40	23	5.8	18		.0	112	15	4.9	146	143	72.3	5.77	2.91
Sept 1	Sept. 10	...	Tr.	10	.20	18	4.5	22		.0	70	11	22	128	127	64.2	3.77	1.9
Sept. 11	Sept. 20	...	108	18	.30	29	6.3	12		.0	98	12	5.1	122	122	61.5	3.37	1.7
Sept. 21	Sept. 29	...	...	...	...	...	...	...	...	...	...	...	...	854	130	65.6	19.0	9.56
Oct. 1	Oct. 10	...	20	13	.10	25	4.6	22		.0	113	12	7.1	130	145	72.9	20.8	10.5
Oct. 11	Oct. 20	...	2	12	.10	26	6.4	20		.0	118	12	7.6	134	143	72.2	20.8	10.5
Oct. 21	Oct. 31	...	24	11	.10	25	5.6	18		.0	116	12	6.1	138	136	69.3	4.96	2.5
Nov. 1	Nov. 10	0	.2	13	.5	26	5.1	18		.0	118	12	6.1	136	128	64.6	4.96	2.5
Nov. 11	Nov. 20	...	8	16	.15	26	5.9	17		.0	117	22	7.1	144	117	58.8	4.96	2.5
Nov. 22	Nov. 30	2	....	14	.10	25	4.8	19		.0	104	17	7.1	134	114	57.7	4.96	2.5
Dec. 1	Dec. 10	2	16	10	.10	28	6.2	18		.0	118	14	6.1	130	146	73.6	14.7	7.4
Dec. 11	Dec. 20	20	118	15	.05	28	5.0	16		.0	120	12	7.1	156	323	163	192	96.8
Dec. 21	Dec. 31	30	22	13	.05	....	4.6	15		.0	86	15	5.6	120	212	107	79.3	40.0
Mean		...	55	16	b.15	26	5.7	18		.0	102	14	7.3	158	313	160	.....	.....
Percent of anhydrous residue		...	.....	11.7	0.1	19.0	4.2	13.1		36.4	....	10.2	5.3	....	.....	.....	.....	.....

a Abnormal. Computed as HCO_3 in the average.

b Mean of Fe values after July 1.

Mineral analyses of water from Santa Ana River above Mentone—Continued.

Date. From—	Date. To—	Turbidity.	Suspended matter.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).[a]	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.	Mean discharge. Acre-feet per day.	Mean discharge. Cubic feet per second.	Run-off per square mile (cubic feet per second).
1907.	1908.																
Dec. 31	Jan. 9	Tr.	....	27	0.02	33	4.9	13	2.4	110	28	.....	3.6	150	106.9	53.9	2,960
1908.																	
Jan. 10	Jan. 19	Tr.	....	22	.11	29	4.5	19	.0	111	19	1.2	3.7	148	115.8	58.4	3,208
Jan. 20	Jan. 29	25	45	25	.05	27	4.5	20	.0	99	21	.66	3.4	143	245.1	123.6	6,791
Jan. 30	Feb. 8	10	....	23	.13	29	6.0	18	.0	106	21	.44	3.9	141	252.8	127.5	7,005
Feb. 9	Feb. 18	5	....	20	.05	26	5.7	21	.0	109	20	.32	3.2	138	230.6	116.3	6,390
Feb. 19	Feb. 28	5	....	22	.18	29	6.4	15	Tr.	120	20	1.1	3.7	141	290.3	146.4	8,044
Feb. 29	Mar. 9	Tr.	....	20	.15	31	6.5	16	.0	118	16	.10	3.0	141	332.6	167.7	9,214
Mar. 10	Mar. 19	Tr.	....	24	.15	24	5.4	22	.0	118	20	.54	4.9	141	189.0	95.3	5,236
Mar. 20	Mar. 29	Tr.	....	26	.02	23	5.2	14	.0	117	18	.80	3.0	139	233.4	117.7	6,466
Mar. 30	Apr. 8	5	....	25	.11	26	5.5	15	.0	116	24	1.0	3.5	142	234.0	118.0	6,483
Apr. 9	Apr. 18	5	....	23	.05	25	5.3	14	.0	109	23	6.0	3.0	134	175.6	88.5	4,862
Apr. 19	Apr. 28	5	....	22	.08	25	3.9	14	.0	107	23	2.0	3.5	162	201.9	101.8	5,593
Apr. 29	May 8	Tr.	....	25	.08	24	6.7	15	.0	104	18	1.0	3.0	130	186.6	94.1	5,170
May 9	May 18	5	....	28	.10	24	7.1	15	.0	112	16	.80	3.5	142	150.3	75.8	4,109
May 19	May 28	5	....	29	.12	21	4.8	14	.0	100	20	1.3	3.5	137	129.7	65.4	3,593
May 29	June 7	Tr.	....	27	.18	25	5.3	16	.0	112	23	.70	2.6	149	129.7	65.4	3,593
June 8	June 17	Tr.	....	19	.18	31	7.4	14	.0	109	30	.20	4.0	128	121.8	61.4	3,373
June 18	June 27	Tr.	....	22	.08	24	5.5	16	.0	110	20	1.9	3.0	135	117.0	59.0	3,242
June 28	July 7	5	....	23	.20	25	4.6	18	.0	115	17	.34	4.0	136	121.4	61.2	3,362
July 8	July 17	Tr.	....	28	.25	25	7.8	13	.0	116	16	.38	4.0	140	132.3	66.7	3,664
July 18	July 27	Tr.	....	23	.23	24	7.4	17	.0	110	13	.90	4.0	138	125.1	63.1	3,466
July 28	Aug. 6	5	....	20	.14	25	9.1	15	.0	117	28	.35	4.5	139	129.7	65.4	3,593
Aug. 7	Aug. 16	130	128	23	.35	21	7.9	17	.0	120	15	.....	2.8	146	130.9	66.0	3,626
Aug. 17	Aug. 26	Tr.	....	17	.37	23	8.1	15	.0	106	14	.70	3.5	122	125.0	63.0	3,461
Aug. 27	Sept. 5	5	....	23	.20	28	10	15	1.2	118	29	.70	3.5	178	122.8	61.9	3,401
Sept. 6	Sept. 15	8	....	17	.15	27	7.2	13	.0	121	14	.80	3.0	134	121.0	61.0	3,351
Sept. 16	Sept. 25	70	142	23	.33	24	7.1	14	.0	122	14	.20	3.5	142	122.0	61.5	3,379
Sept. 26	Oct. 5	Tr.	....	23	.20	21	6.6	11	.0	121	17	Tr.	3.1	145	106.7	53.8	2,956
Oct. 6	Oct. 15	Tr.	....	24	.44	23	7.6	14	.0	127	19	Tr.	3.2	146	117.2	59.1	3,247
Oct. 16	Oct. 25	Tr.	....	27	.10	24	6.2	17	.0	121	14	.34	3.0	146	109.5	55.2	3,033
Oct. 26	Nov. 4	Tr.	....	20	.15	24	1.8	17	.0	115	16	Tr.	4.0	137	109.1	55.0	3,022
Nov. 5	Nov. 14	4	....	78	.24	23	5.7	39	45	80	25	Tr.	6.0	256	82.1	41.4	2,274
Nov. 15	Nov. 24	15	16	36	.08	24	6.4	32	.0	121	22	Tr.	4.5	162	81.9	41.3	2,269
Nov. 25	Dec. 4	Tr.	....	29	.12	24	6.9	23	.0	115	22	1.8	4.1	144	88.9	44.8	2,461
Dec. 5	Dec. 14	Tr.	....	22	.18	25	6.7	31	.0	115	20	.70	7.0	142	89.3	45.0	2,472
Dec. 15	Dec. 24	Tr.	....	24	.08	25	6.1	17	.0	117	18	.36	4.9	141	81.7	41.2	2,263
Dec. 25	Dec. 31	4	....	21	.10	25	8.9	29	.0	120	22	.26	5.0	144	80 7	40.7	2,236
Mean		8	....	25	.16	25	6.3	18	.0	116	20	.75	3.8	145	149.2	75.22	4,131
Per cent of anhydrous residue		....	....	16.0	0.1	16.0	4.0	11.6	36.6	.....	12.8	0.5	2.4	.....	.....	.....	.....

[a] The values given for CO_3 are abnormal and are computed as HCO_3 in the average.

CHARACTER OF WATER NEAR CORONA.

Samples of water were collected daily during 1908 by Mrs. W. C. Warner from the bridge near Auburndale, a small settlement on the banks of the Santa Ana, about 3 miles from Corona, from which it may be reached by driving, and about 5 miles below the entrance to Santa Ana Canyon.

Near Riverside, at what is known as Riverside Narrows, the water of the Santa Ana is brought to the surface by bed-rock obstructions, and it gradually increases in volume until it reaches Santa Ana Canyon. At Auburndale the surface flow is continuous throughout the year, and the river contains not only the original waters of the Santa Ana, but added waters from artesian wells which are located above, especially near San Bernardino and Riverside. However, as all these

waters have their origin in the San Bernardino Mountains, and as all flow through practically the same rock and soil formations, their mineral characteristics should be similar, and the waters of the Santa Ana near Corona should resemble in percentage composition the waters at Mentone; the difference is an increase in the mineralization of the waters near Corona, due to the effect of seepage, and measures that effect. The river bottom at Auburndale is wide and sandy, and the slopes are moderate.

The analyses (pp. 104–105) show that on reaching Corona, Santa Ana River has become charged with almost two and a half times as much mineral matter in solution as it held on leaving the mountains. Although all the constituents, even silica, share this increase, the percentage composition of the anhydrous residue shows that a decided change has taken place in the character of the water. Chlorine exhibits the greatest proportional increase, the total amount rising from 2.4 to 11.5 per cent. The alkalies exhibit the next largest rise, calcium and normal carbonates show smaller changes, and the remaining radicles show reductions, silica leading, with a decrease of 7.3 per cent, while the bicarbonates have fallen 3.6 per cent. It is thus evident that the changes that have occurred in the nature of the dissolved material are large and important.

Calcium has been added to a much greater extent than magnesium, the ratio of magnesium to calcium falling to 1 to 4.7—the smallest relative magnesium value noted so far in the samples. The increase in calcium is attended by an increase in bicarbonates almost exactly in ratio of composition as calcium bicarbonate, although it is probable that some, at least, of the magnesium increase found is the result of solution of magnesium carbonate. Sulphates show an increase of 22 parts per million, probably in great part due to solution of sulphates of the alkalies.

That the seasonal fluctuation is more marked in the water of the river at Corona is largely due to the fact that there is longer surface flow and relatively less seepage in winter than in summer, the result being that in the wet season less mineral matter is picked up in transit.

Turbidity also shows more marked variations in the lower than in the upper regions. Water returned to the river from irrigation ditches is turbid, while rain falling on the loose, sandy soil of the region sends to the streams water containing a large amount of suspended material. The high turbidity recorded in late September and early October in 1908 was due to severe storms throughout the drainage area.

The water is far inferior to that in the river above Mentone. Although it is still highly useful for irrigation, it has become hard, needing treatment to render it fit for use in boilers. Like all other waters

high in carbonates and sulphates, it is poor for domestic use, for not only does it consume large quantities of soap, but foodstuffs cooked in it lose flavor and actual nutrient value. It would need sedimentation or coagulation and filtration to render it fit for a municipal supply.

Mineral analyses of water from Santa Ana River near Corona.

[Parts per million unless otherwise stated.]

Date.		Turbidity.	Suspended matter.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na + K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.
From—	To—													
1907. Dec. 31	1908. Jan. 9	15	32	30	0.08	79	12	39	0.0	244	51	2.0	41	362
1908.														
Jan. 10	Jan. 19	135	102	27	.12	75	12	52	.0	249	55	2.1	41	366
Jan. 20	Jan. 29	680	757	28	.21	60	12	46	.0	212	53	2.7	34	329
Jan. 30	Feb. 8	675	911	30	.38	66	12	45	.0	206	54	.9	30	317
Feb. 9	Feb. 18	450	489	27	.37	55	12	50	.0	201	52	1.6	29	313
Feb. 19	Feb. 28	50	96	25	.15	66	12	36	.0	210	49	2.9	25	292
Feb. 29	Mar. 9	55	128	23	.15	61	11	36	.0	205	45	2.1	24	285
Mar. 10	Mar. 19	20	49	28	.45	53	7.8	40	.0	227	46	3.5	28	312
Mar. 20	Mar. 29	10	.....	39	.24	60	12	41	4.8	239	17	3.0	38	344
Mar. 30	Apr. 8	20	42	29	.17	61	13	49	1.2	232	48	Trace.	38	342
Apr. 9	Apr. 18	Trace.	.....	31	.05	62	12	47	9.4	230	56	3.0	45	363
Apr. 19	Apr. 28	10	.....	31	.05	63	12	51	.0	251	39	3.0	46	362
Apr. 29	May 8	Trace.	.....	26	.20	62	18	47	.0	246	35	4.0	45	347
May 9	May 18	Trace.	.....	28	.14	59	12	46	.0	240	40	2.0	41	342
May 19	May 28	4	.....	32	.17	64	13	50	11	222	42	3.8	43	359
May 29	June 7	Trace.	.....	29	.18	62	9.3	50	4.8	237	43	2.0	47	352
June 8	June 17	Trace.	.....	35	.23	60	13	48	18	210	47	2.5	35	361
June 18	June 27	Trace.	.....	29	.07	60	12	52	7.2	229	35	1.6	45	336
June 28	July 7	5	.....	30	.18	59	13	44	9.6	218	36	1.6	43	336
July 8	July 17	Trace.	.....	33	.70	59	13	49	9.6	218	41	1.6	43	356
July 18	July 27	6	.....	32	.18	57	13	52	7.2	223	35	2.2	44	341
July 28	Aug. 6	5	.....	38	.12	57	12	47	4.8	232	33	1.5	41	341
Aug. 7	Aug. 16	7	.....	39	.08	58	12	59	.0	243	32	1.3	43	342
Aug. 17	Aug. 26	Trace.	.....	41	.29	57	15	51	4.8	222	40	3.0	41	349
Aug. 27	Sept. 5	Trace.	.....	34	.18	56	12	48	20	195	36	2.0	34	317
Sept. 6	Sept. 15	Trace.	.....	38	.15	59	13	48	12	226	38	1.9	45	350
Sept. 16	Sept. 25	[a] 150	[a] 320	30	.15	60	14	47	1.2	245	43	2.0	49	364
Sept. 26	Oct. 5	60	57	33	.20	61	13	48	4.8	250	42	.....	50	368
Oct. 6	Oct. 15	8	.....	33	.11	61	14	49	2.4	246	38	2.2	44	344
Oct. 16	Oct. 25	10	.....	35	.05	71	17	58	.0	256	55	1.9	47	418
Oct. 26	Nov. 4	Trace.	.....	30	.22	60	11	48	.0	249	50	2.4	44	348
Nov. 5	Nov. 14	6	.....	30	.08	61	13	49	.0	256	36	1.9	48	356
Nov. 15	Nov. 24	7	.....	31	.08	61	14	52	.0	249	35	2.2	44	352
Nov. 25	Dec. 4	4	.....	31	.25	62	14	55	2.4	248	38	2.5	49	370
Dec. 5	Dec. 14	12	14	29	.15	61	14	48	.0	254	44	3.6	49	362
Dec. 15	Dec. 24	4	.....	32	.08	63	14	64	.0	259	37	3.8	47	361
Dec. 25	Dec. 31	Trace.	.....	27	.04	63	15	66	2.4	246	50	4.0	48	366
Mean		65	.....	31	.18	61	13	49	3.7	233	42	2.3	41	347
Per cent of anhydrous residue		.....	.....	8.7	0.0	17.1	3.6	13.8	33.0	.....	11.7	0.6	11.5	.....

[a] September 25, turbidity 1,500, suspended matter, 3,200.

SAN LUIS REY RIVER.

DESCRIPTION.

San Luis Rey River rises on the western slope of the Coast Range in the northern part of San Diego County and, flowing westward, discharges its waters into the Pacific Ocean near the town of Oceanside. It has numerous small tributaries, none of which rise at elevations exceeding 5,000 feet above sea level. For a portion of its length the river flows through a deep, narrow canyon, but below the canyon the grade is light and the water soon disappears in a sandy gravelly bed, rising to the surface again near the town of Pala. From Pala to the ocean, a distance of about 25 miles, its grade continues light. The discharge of the river is irregular, most of the water flowing in the late winter and early spring. During the summer the flow is very slight.

Soil covering is good throughout the basin, and there is a considerable growth of brush and grass. On the upper reaches of the stream the country is rolling, and several small valleys are under cultivation for raising grain, olives, and lemons, or are used for the pasturage of stock.

CHARACTER OF WATER.

Samples for this investigation were collected daily by the gage reader at the gaging station near Pala Mills.[a] The stream at this point is narrow and swift, its bed is composed of coarse gravel and rocks, and the banks are low and subject to overflow at high stages.

At times of flood the river carries a great quantity of coarse material in suspension; during the summer months the water is fairly clear but it then carries considerable dissolved mineral matter, largely bicarbonates, calcium, and magnesium, which may, however, be removed by treatment. The total amount of dissolved material present is not large as compared with that in the coast streams farther north. (See analyses.)

The water is not at present used industrially except for irrigation, but it is admirably adapted for agricultural purposes as well as for those industries in which a moderately hard water is not objectionable. For use in boilers the water would require softening.

[a] For data concerning gage heights and discharge see Water-Supply Papers U. S. Geol. Survey Nos. 100, 134, 177, and 213.

Mineral analyses of water from San Luis Rey River at Pala.

[Parts per million unless otherwise stated.]

Date.		Turbidity.	Suspended matter.	Silica (SiO_2).	$Al_2O_3+Fe_2O_3$.	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Total solids.	Mean discharge.	
From—	To—														Acre-feet per day.	Cubic feet per second.
1906.	1906.															
Jan. 1	Jan. 10	....	20	41	1.2	44	14	92	0.1	0.0	178	63	47	336	23.4	11.8
Jan. 11	Jan. 20	....	358	35	1.8	40	12	86	6.8	.0	56	54	7.7	346	69.8	35.2
Jan. 21	Jan. 30	....	80	35	0.8	41	14	48	4.5	.0	166	64	47	294	36.1	18.2
Jan. 31	Feb. 9	....	584	37	1.8	46	14	41	3.8	.0	176	69	48	354	21.8	11.0
Feb. 10	Feb. 19	....	380	33	3.4	37	13	30	4.5	.....	.....	.....	11	.....	346	86.9	43.8
Feb. 20	Mar. 1	....	194	29	3.2	39	14	34	3.5	.0	168	63	46	320	57.5	29.0
Mar. 3	Mar. 10	....	266	37	2.2	41	14	37	3.1	.0	168	60	47	340	61.3	30.9
Mar. 22	Mar. 31	....	1,724	27	3.8	20	6.3	18	3.2	.0	89	20	17	224	5,284	2,664
Apr. 1	Apr. 9	....	240	28	8.4	28	12	20	1.6	.0	111	34	27	260	952	480
Apr. 11	Apr. 20	....	.....	23	5.2	30	9.5	20	3.3	.0	127	36	26	....	538	271
Apr. 21	Apr. 30	....	76	29	2.4	35	9.8	33	3.8	.0	131	34	28	262	315	159
May 1	May 10	....	22	29	3.8	29	9.6	17	4.5	.0	132	35	29	252	317	160
May 11	May 20	....	32	29	3.4	31	11	25	3.7	.0	138	41	30	266	315	159
May 21	May 31	....	22	27	4.0	33	11	24	3.1	.0	136	37	30	276	309	156
June 1	June 10	....	20	29	3.4	44	13	34	4.1	.0	144	48	32	276	224	113
June 11	June 20	....	12	34	5.0	44	12	27	2.2	[a]13	132	47	35	312	104	52.7
June 21	June 30	....	20	40	4.4	44	12	42	3.3	.0	160	46	34	292	62.1	31.3
July 2	July 9	....	116	.....	.....	.....	.....	.....	.....	[a]2.5	166	.....	41	242	37.7	19.0
					Fe.											
July 11	July 20	...	54	31	.06	39	12	42		.0	169	52	39	314	37.7	19.0
July 21	July 30	...	Tr.	27	.08	45	14	44		.0	175	54	39	342	37.7	19.0
Aug. 1	Aug. 10	....	Tr.	33	.10	58	14	50		.0	167	59	38	338	27.6	13.9
Aug. 11	Aug. 20	....	190	29	.05	43	13	45		.0	171	56	40	338	25.2	12.7
Aug. 21	Aug. 31	....	16	36	.13	48	14	51		.0	182	58	44	348	10.6	5.36
Sept. 1	Sept. 10	....	2	42	.20	46	14	26		.0	176	60	42	348	5.95	3.0
Sept. 11	Sept. 20	....	20	36	.10	46	14	50		.0	174	63	41	342	10.1	5.10
Sept. 21	Sept. 30	....	6	33	.20	48	13	60		.0	196	54	41	338	5.95	3.0
Oct. 1	Oct. 10	....	20	23	.20	56	18	58		.0	197	61	46	346	5.95	3.0
Oct. 11	Oct. 20	....	40	28	.15	48	14	36		.0	197	68	44	346	5.95	3.0
Oct. 21	Oct. 31	20	22	27	.25	48	14	50		.0	200	60	46	354	5.95	3.0
Nov. 1	Nov. 10	5	12	30	.15	46	15	49		.0	198	84	46	354	5.95	3.0
Nov. 11	Nov. 20	2	2	31	.05	48	14	62		.0	203	67	48	358	5.95	3.0
Nov. 21	Nov. 30	10	46	31	.10	50	16	53		.0	201	65	52	352	37.5	18.9
Dec. 1	Dec. 10	10	28	31	.04	46	24	50		.0	206	64	54	368	32.1	16.2
Dec. 11	Dec. 12	....	.....	.....	.....	.....	.....	.....	.....	[a]24	114	.....	50	....	556	280
Dec. 26	Dec. 31	60	56	22	.01	40	13	.....	.....	.0	170	.....	60	400	335	169
Mean		....	142	31	[b].12	42	13	44		.0	163	53	39	321	285	143
Per cent of anhydrous residue		....	.....	10.3	0.0	13.9	4.3	14.6		26.5	.....	17.5	12.9	....	.....	.....

[a] Abnormal. Computed as HCO_3 in the average. [b] Mean of Fe values after July 1.

SANTA YSABEL CREEK.

DESCRIPTION.

Santa Ysabel Creek rises on the western slopes of the Volcan Range, in the San Jacinto Mountains, and flows slightly to the southwest, emptying into the Pacific Ocean. In its upper course it is called Santa Ysabel Creek, lower down Bernardo River, and still nearer the ocean San Dieguito River. In this report the name Santa Ysabel is applied to the entire stream.

In its upper valley the creek traverses a rough, broken country, through which the streams have cut deep gullies. Leaving the mountains it sinks into the sands of the San Pasqual Valley, except during the rainy season, when there is surface flow. Like all the southern

coastal streams, Santa Ysabel Creek is torrential in character, the maximum flow occurring in the early spring.

STREAM DISCHARGE.

In 1908 the maximum discharge of this stream occurred during January and February, the greatest average being for the ten-day period from February 9 to 18, inclusive, when it was 120.6 acre-feet a day. From January 20 to March 9, a period of seven weeks, 52.9 per cent of the total run-off for the year occurred, while in the twenty days from January 30 to February 18, 23.8 per cent of the total flow for the year was carried past the gage. The river was dry from July 10 until September 26, a period of seventy-eight days, or 21.4 per cent of the year. It is thus apparent that one-fourth of the total discharge occurred within three weeks, while during approximately one-fourth of the whole year there was no flow whatever. This condition is characteristic not only of Santa Ysabel Creek but of all the torrential streams of the San Diego mesas, and has a decided effect upon the appearance of the streams of the region as well as upon the agricultural development of the section. Most of the streams flow across the mesa lands in narrow canyons with abrupt, precipitous walls. They rush down these gorges with great violence in the rainy season, oftentimes overflowing their banks and spreading out over the mesas; but in the summer time no sign of flowing water is apparent, and the canyon floors become dry beds of sand and gravel. The waters of Santa Ysabel Creek are used for irrigation in San Pasqual Valley, but in years of abnormal flow, when the amount of water obtainable is insufficient, all the crops suffer. If agriculture were to become more extensive than at present it would be necessary to impound and store the flood waters of the streams of this region and hold them over until the irrigation season.

CHARACTER OF WATER.

Samples of water were taken daily during periods of surface flow in 1908 by F. S. Potts at the Potts ranch, about 13 miles east of the town of Escondido, where the creek leaves its canyon and enters San Pasqual Valley. The flow at this place is almost continuous, the stream becoming dry in summer only in exceptional years. The bed of the creek is of fine shifting sand, the slope is steep, and the current is consequently swift. The results of the analyses are shown in the accompanying table.

Mineral analyses of water from Santa Ysabel Creek at San Pasqual near Escondido, Cal.

[Drainage area, 128 square miles. Quantities in parts per million unless otherwise stated.]

Date.		Turbidity.	Suspended matter.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.	Mean discharge.		Run-off per square mile (cubic feet per second).
From—	To—														Acre-feet per day.	Cubic feet per second.	
1907. Dec. 31	1908. Jan. 9	5	.....	40	0.11	37	16	43	0	158	33	2.0	40	277	21.8	11	0.0859
1908.																	
Jan. 10	Jan. 19	5	.....	37	.17	35	14	42	0	156	36	.76	39	270	21.6	10.9	.0851
Jan. 20	Jan. 29	90	274	39	.25	29	12	37	0	137	31	.48	33	236	99.0	49.9	.3898
Jan. 30	Feb. 8	30	38	40	.35	28	11	40	0	122	33	.16	29	232	117.4	59.2	.4624
Feb. 9	Feb. 18	40	151	38	.21	27	10	35	0	116	26	.48	28	209	120.6	60.8	.4750
Feb. 19	Feb. 28	8	.....	44	.18	25	8.2	33	2.4	134	32	.68	31	237	81.3	41	.3203
Feb. 29	Mar. 9	19	.....	41	.18	22	12	33	0	133	28	1.1	28	214	112.3	56.6	.4422
Mar. 10	Mar. 19	5	.....	47	.08	26	11	32	0	138	32	4.0	32	243	67.2	33.9	.2648
Mar. 20	Mar. 29	15	.....	47	.04	26	13	34	4.3	135	27	1.9	31	234	51.4	25.9	.2023
Mar. 30	Apr. 8	5	.....	23	.49	26	12	32	0	144	31	1.9	31	241	46.8	23.6	.1843
Apr. 9	Apr. 18	10	.....	32	.30	27	10	37	7.4	136	35	.40	33	261	30.3	15.3	.1117
Apr. 19	Apr. 28	10	.....	38	.20	26	12	33	0	144	28	.50	31	244	51.2	25.8	.2015
Apr. 29	May 8	10	.....	45	.13	26	12	35	0	148	24	2.1	32	241	35.1	17.7	.1383
May 9	May 18	Tr.	.....	43	.18	27	9.6	33	7.2	132	25	1.2	32	238	32.5	16.4	.1281
May 19	May 28	Tr.	.....	47	.09	26	12	35	4.8	138	27	.96	33	247	19.0	9.6	.0750
May 29	June 7	5	.....	51	.21	27	12	36	0	154	26	1.2	34	250	15.0	7.54	.0589
June 8	June 17	Tr.	.....	47	.06	28	13	37	0	159	24	Tr.	37	254	10.0	5.07	.0396
June 18	June 27	Tr.	.....	50	.06	28	14	42	7.2	154	29	.48	40	273	7.54	3.8	.0297
June 28	July 7	Tr.	.....	49	.13	32	13	48	0	179	25	.72	48	293	2.10	1.06	.0083
July 8	July 10	10	.....														
Sept. 26	Oct. 5	60	25	54	.02	33	18	54	1.2	206	43	.02	58	349	.56	.28	.0018
Oct. 6	Oct. 15	Tr.	.....	54	.24	33	18	46	0	206	31	.86	60	348	.46	.23	.0018
Oct. 16	Oct. 25	45	47	49	.05	30	16	54	0	185	30	.68	44	302	2.08	1.05	.0082
Oct. 26	Nov. 4	Tr.	.....	49	.10	30	13	48	0	190	29	.08	45	317	1.69	.85	.0066
Nov. 5	Nov. 14	6	.....	48	.28	30	15	61	2.4	181	32	Tr.	48	299	3.29	1.66	.0129
Nov. 15	Nov. 24	4	.....	42	.16	32	17	55	0	181	30	Tr.	46	289	6.64	3.35	.0261
Nov. 25	Dec. 4	40	66	40	.18	30	14	52	0	167	33	.30	42	282	12.9	6.5	.0508
Dec. 5	Dec. 14	10	.....	47	.05	30	15	52	0	176	29	.72	43	289	10.3	5.2	.0406
Dec. 15	Dec. 24	Tr.	.....	49	.18	30	15	58	0	172	28	.44	43	286	9.60	4.84	.0378
Dec. 25	Dec. 31	6	.....	47	.28	34	16	54	0	173	30	.24	44	292	10.7	5.4	.0422
Mean		14	.....	44	.17	29	13	42	1.3	160	30	.84	38	260	34	17	.135
Per cent of anhydrous residue		.....	.....	16.0	0.1	10.5	4.7	15.3	28.4	.....	10.9	0.3	13.8	.....	.....	.....	.....

Bicarbonates comprise a large part of the dissolved material in the water of this creek, while next in importance is silica, which attains a very high value, ranging from 38 parts per million with total solids at 209 to 54 parts per million with total solids at 349. The alkalies, which come next in order of quantity, show marked variations, and it is probable that a large part of the variation in total solids is due to the fluctuations of dissolved alkaline chlorides and silicates. Chlorides are extremely high, varying from 28 to 60 parts per million.

For irrigation the quality of the water is very good. A small amount of normal carbonates is occasionally present, and as a result black alkali might at times be deposited, but the quantity would be negligible, and evil results could be prevented by proper drainage of the lands.

The water of this creek is hard, but the hardness is largely of the temporary character which can be removed by preheating or chemical treatment. The addition of a little soda ash to the water will remove

considerable of the lime salts and reduce the tendency to form scale. In boilers not frequently blown out this water might cause corrosion by reason of its high content of chlorides, and if the salts were allowed to concentrate greatly foaming might also occur. For drinking the water should cause no trouble if filtered or boiled before being used. The population of the district is not yet sufficiently dense to warrant the erection of filtration plants for any of the settlements.

COTTONWOOD CREEK.

DESCRIPTION.

Cottonwood Creek is a torrential stream rising on the western slopes of the San Jacinto Mountains and flowing southwestward to the Tia Juana, near the boundary between California and Mexico. The country through which it passes is very rough. The bed rock is a granite of loose texture and the soil covering is good. A growth of scrub trees, mainly oak, occurs throughout the basin.

CHARACTER OF WATER.

Samples of water were collected daily during 1908—except in July, August, September, and October, when the stream bed was dry—at Barrett dam, about 35 miles east of San Diego and about 8 miles north of the Mexican boundary, through the courtesy of William Clayton, manager for the Southern California Mountain Water Company, which is constructing the dam. The collector was M. M. O'Shaughnessy.

Fluctuations in the mineral content of this stream are irregular (see analyses, p. 113), as would be expected from the small size and semiarid character of its drainage area. A change in dissolved material manifests itself after each rainfall, and the relation between discharge and quality for the winter months is therefore far less uniform than that for the summer or fall. In 1908 the least dissolved mineral matter was found for the period including late February and early March, the amount increasing steadily up to the time when surface flow ceased. It is probable that the subsurface flow during July, August, September, and October carried about 500 parts per million of dissolved mineral matter, approaching in character that recorded for the composite sample of June 28 to July 8.

The water is alkaline carbonate in type, calcium being second in importance to the alkali bases and chlorine being the second most prominent acid radicle. The increase in alkalies and chlorine is most conspicuous when an increase in total solids occurs, carbonates sharing the rise with chlorides. Normal carbonates appear in most of the analyses, and their presence, although in small quantities, is a danger sign for irrigation.

Considering the character of the region through which the stream flows, the water is fair for municipal use. It is hard, both temporary and permanent hardness being high. Soda ash or some similar softening compound should be added if the water is to be used for steaming, and much soft scale will then be formed, which must frequently be removed. The corrosion of boilers that is likely to result can not well be prevented by treating the water.

Mineral analyses of water from Cottonwood Creek at Barrett dam, San Diego County.

[Parts per million unless otherwise stated.]

Date.		Turbidity.	Suspended matter.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.	Mean discharge.	
From—	To—														Acre-feet per day.	Cubic feet per second.
1907. Dec 31	1908. Jan. 9	5	.....	42	0.05	77	20	75	0.0	164	55	0.5	59	423	20.19	10.18
1908. Jan. 10	Jan. 19	15	.....	39	.18	56	20	66	2.4	261	62	1.0	61	431	25.98	13.10
Jan. 20	Jan. 29	105	88	38	.12	61	14	42	.0	237	57	.8	53	402	93.28	47.03
Jan. 30	Feb. 8	160	125	39	.28	47	18	59	.0	205	55	.26	48	361	127.73	64.4
Feb. 9	Feb. 18	45	67	40	.48	42	18	60	.0	199	55	1.2	42	341	140.18	70.7
Feb. 19	Feb. 28	30	14	43	.09	31	15	64	4.8	200	53	.69	49	356	78.94	39.8
Feb. 29	Mar. 9	50	40	39	.38	37	11	50	14	168	47	1.3	45	328	104.13	52.5
Mar. 10	Mar. 19	15	.....	43	.30	44	16	54	3.6	217	52	1.4	53	380	55.34	27.9
Mar. 20	Mar. 29	12	.....	43	.27	48	18	63	.0	242	53	2.0	54	384	49.12	24.77
Mar. 30	Apr. 8	10	.....	53	.05	45	17	61	9.6	220	38	2.1	54	341	35.20	17.75
Apr. 19	Apr. 28	15	.....	59	.04	47	19	62	.0	215	50	2.0	63	353	24.93	12.57
Apr. 29	May 8	Tr.	.....	42	.15	50	24	60	.0	253	55	.9	56	410	25.03	12.62
May 9	May 18	5	.....	42	.02	50	23	68	2.4	251	52	1.0	60	416	19.22	9.69
May 19	May 28	Tr.	.....	46	.35	52	21	68	8.4	245	55	1.5	64	431	14.53	7.33
May 29	June 7	Tr.	.....	43	.18	49	19	70	7.2	242	50	.56	66	417	12.81	6.46
June 8	June 17	Tr.	.....	48	.08	53	22	64	6.0	268	43	.82	66	423	7.44	3.75
June 18	June 27	Tr.	.....	49	.18	54	22	75	9.6	278	54	Tr.	70	455	3.93	1.98
June 28	July 7	5	.....	51	.13	56	24	82	.0	317	41	3.5	78	482	1.21	.61
July 8	July 9	Tr.	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Nov. 6[a]	Nov. 15	Tr.	.....	46	.12	55	23	91	4.8	298	39	Tr.	86	467	8.41	4.24
Nov. 16	Nov. 25	Tr.	.....	46	.16	54	23	85	2.4	286	43	Tr.	73	465	8.52	4.30
Nov. 26	Dec. 4	Tr.	.....	42	.14	54	26	84	2.4	273	61	1.3	73	455	10.95	5.52
Dec. 5	Dec. 14	Tr.	.....	44	.14	55	23	91	4.8	264	61	.80	74	454	10.33	5.21
Dec. 15	Dec. 24	10	15	51	.26	56	24	91	2.4	295	58	.74	73	479	13.47	6.79
Dec. 25	Dec. 31	Tr.	.....	42	.32	57	27	78	6.0	300	65	.32	73	474	13.15	6.63
Mean		19	.....	44	.18	51	20	69	3.7	246	52	1.0	62	413	37.66	19
Percent of anhydrous residue		.....	.....	10.4	0.0	12.0	4.7	16.3	29.5	.....	12.3	0.2	14.6	.....	.....	.....

[a] Creek dry during summer.

NOTES ON MUNICIPALITIES.

Reports were received from 58 settlements in the south Pacific Ocean drainage area. Sixteen of these towns and cities take their entire water supply from surface streams, 14 derive part of their supply from streams and a part from wells, 27 are supplied entirely by wells, and 1 uses a mineral spring. Only 6 places filter the surface supplies, the other 52 using no method of purification.

The statistical data regarding water supply are presented in detail in the following table:

Statistics of municipal water supplies in south Pacific Ocean drainage area.

Settlement	Drainage basin.	Population.	Adjacent to—	Source of supply.	Nature of system.	Ownership.	Methods used for purification.	Daily consumption per capita (gallons).	Nature of sewerage system.	Ultimate disposal of sewage.
Alhambra	San Gabriel River.	[a] 800	.....	Wells and stream	Gravity and pumping.	San Gabriel Valley Water Co.	None	No data.	None	
Anaheim	Santa Ana River.	1,621	Santa Ana River.	Wells	Pumping	Municipal	do	200	do	
Azusa	San Gabriel River.	[a] 863	San Gabriel River.	Wells and stream	Gravity	do	do	175	Sanitary	Used for irrigation.
Boulder Creek	Monterey Bay	[b] 1,000	San Lorenzo River.	Stream	do	(?)	do	No data.	.....	
Colton	Santa Ana River.	1,300	Santa Ana River.	Artesian wells	Gravity and pumping.	Municipal	do	do	None	
Compton	Los Angeles River.	[b] 1,000	Compton Creek	Wells	Pumping	Compton Water and Light Co.	do	87	do	
Corona	Santa Ana River.	[a] 1,434	Santa Ana River.	Wells and stream	Gravity and pumping.	Municipal	do	.....	do	
Coronado	San Diego Bay	[a] 935	San Diego Bay	Streams	Gravity	Coronado Water Co.	do	200	Sanitary	San Diego Bay.
Covina	San Gabriel River.	[b] 1,600	San Antonio Creek.	do	do	Covina City Water Co.	do	30	None	
Elsinore	Lake Elsinore	[a] 279	Lake Elsinore	Mineral spring	Pumping	Municipal	do	60	.....	
Escondido	San Luis Rey River.	948	Escondido Creek.	San Luis Rey River.	Gravity	All real estate owners.	do	.....	Sanitary	Valley about 1 mile below city.
Fullerton	San Gabriel River.	[b] 2,200	Coyote Creek	Wells	Pumping	A. L. Selig	do	.....	None	
Gilroy	Monterey Bay	1,933	Uvas Creek	Uvas Creek and wells.	Gravity	Municipal	Sand box filtration.	No data.	Sanitary — septic tank and filter beds.	
Glendale	Los Angeles River.	[b] 2,500	Los Angeles River.	Wells and stream	do	Six different companies.	None	do	None	
Hermosa Beach	Santa Monica Bay.	[b] 800	Pacific Ocean	Wells	Pumping	Hermosa Beach Water Co.	do	.....	Sanitary (ocean front only).	Sand hills.
Hollister	Monterey Bay	1,388	San Benito River.	Infiltration; Pescadero Creek.	Gravity	Hollister Water Co.	Infiltration galleries.	200	Combined system.	Sewer farm.
Hollywood	Santa Monica Bay.	[a] 300	Ballona Creek	Wells	Pumping	Union Hollywood Water Co.	None	No data.	None	
Huntington Park.	Los Angeles River.	[b] 1,800	Los Angeles River.	Artesian wells	do	South Los Angeles Water Co.	do	do	do	
Long Beach	do	12,591	Pacific Ocean	do	do	Long Beach Water Co.	do	300	Sanitary — septic tank.	Pacific Ocean.
Los Angeles	do	275,000	Los Angeles River.	Los Angeles River and wells.	do	Municipal	do	120	Separate systems	Do.

Monrovia	San Gabriel River.	1,470		Artesian wells and streams.	Gravity and pumping.	do	do	No data.	Flood	
Monterey	Monterey Bay	1,825	Monterey Bay	Carmel River	Gravity	Monterey County Water Works.	do	do	Sanitary	Monterey Bay.
National City	San Diego Bay.	1,086	Sweetwater River.	Sweetwater River.	do	Sweetwater Water Co.	do	do	None	
Newport Beach	Santa Ana River.	b 3,000	Pacific Ocean	Artesian wells	Pumping	Newport Beach Water Co.	do	240		
Ocean Park	Santa Monica Bay.	b 3,000	do	Wells	do	City Water Co.	do			
Oceanside	Pacific Ocean	b 800	do	do	Gravity and pumping.	Municipal	do	208	None	
Ontario	Santa Ana River.	757		San Antonio Creek and wells.	do	Municipal and two private companies.	do	20	Sanitary	Sewer farm.
Orange	do	1,531	Santa Ana River.	Wells	Pumping		do	300		
Oxnard	Santa Clara River.	b 2,500	Pacific Ocean	Artesian wells	do	Ventura County Power Co.	do	140		Pacific Ocean.
Pacific Grove	Monterey Bay	1,480	Monterey Bay	Carmel River	Gravity	Monterey County Water Works.	do	No data.	Sanitary	Monterey Bay.
Pasadena	Los Angeles River.	16,705	Arroyo Seco	Stream and wells	Pumping and gravity.	Several companies.	Infiltration galleries.	do	do	Sewer farm.
Paso Robles	Monterey Bay	1,581	Salinas River	Salinas River	Pumping	Paso Robles Light and Water Co.	Infiltration	100	do	Salinas River.
Pomona	Santa Ana River.	6,690	Chino Creek	Tunnel and wells	Gravity	Consolidated Water Co.	do	300	Combined system.	Sewer farm.
Redlands	do	7,369	Santa Ana River.	Streams	do				do	
Redondo Beach	Santa Monica Bay.	1,082	Pacific Ocean	Wells	Pumping	Redondo Water Co.	None			Do.
Riverside	Santa Ana River.	9,855	Santa Ana River.	Artesian wells	Gravity and pumping.	Riverside Water Co.	do	60	Combined system.	Alfalfa fields across river.
Salinas	Monterey Bay	4,177	Salinas River	Wells	Pumping	Monterey County Gas and Electric Co.	do	100	Sanitary	Sewer farm.
San Bernardino	Santa Ana River.	7,648	Santa Ana River.	Artesian wells	do				do	Do.
San Diego	San Diego Bay.	19,860	San Diego Bay.	Streams	Gravity	South California Mountain Water Co.	Mechanical filtration.	100	do	San Diego Bay.
San Jacinto	San Jacinto River.	b 1,000	San Jacinto River.	Artesian wells	Pumping	Municipal	None		None	
San Juan	Monterey Bay	b 500	San Benito River.	Streams	Gravity	do	do			
San Luis Obispo	Pacific Ocean	3,044	South Los Angeles Creek.	Streams and wells.	Gravity and pumping.	do	do	150	Sanitary — septic tanks.	
San Pedro	Los Angeles River.	c 5,618	Pacific Ocean	Wells	Pumping	San Pedro Water Co.	do		Combined	San Pedro Harbor.

a United States census of 1900.

b Estimates by city or town clerk or by health officer; in some cases by Walton Van Winkle from the aforementioned.

c Census of 1906, Blue Book of California.

Statistics of municipal water supplies in south Pacific Ocean drainage area—Continued.

Settlement.	Drainage basin.	Population.	Adjacent to—	Source of supply.	Nature of system.	Ownership.	Methods used for purification.	Daily consumption per capita (gallons).	Nature of sewerage system.	Ultimate disposal of sewage.
Santa Ana	Santa Ana River.	6,107	Santa Ana River.	Wells	Pumping		None	175	Septic tank	Sewer farm.
Santa Barbara	Pacific Ocean	7,415	Pacific Ocean	Mission Creek and wells.	Gravity and pumping.	Municipal and two private companies.	do	80	Combined	Pacific Ocean.
Santa Cruz	Monterey Bay	5,713	San Lorenzo River.	Laguna Creek	Gravity	Municipal	do		Separate systems and septic tanks.	Monterey Bay.
Santa Maria	Santa Maria River.	a 1,500	Santa Maria River.	Wells	Pumping		do	60	None	
Santa Monica	Santa Monica Bay.	b 7,223	Pacific Ocean	Stream and wells	Gravity and pumping.	Four companies	do	60	Sanitary—septic tank.	Pacific Ocean.
Santa Paula	Santa Clara River.	2,300	Santa Clara River.	Streams	Gravity	Santa Paula Water Co.	do		None	
Sawtelle	Santa Monica Bay.			Wells	Pumping	Two companies	do	25		
South Pasadena	Los Angeles River.	a 4,000	do	do	do	Three companies	do		None	
Upland	Santa Ana River.	a 2,500		Stream and wells	do	Two companies	do		do	
Ventura	Ventura River.	2,605	Ventura River.	Ventura River	Gravity and pumping.	Ventura County Power Co.	do	250		Do.
Vernon	Los Angeles River.		Los Angeles River.	Wells	Pumping	South Los Angeles Water Co.	do			
Watsonville	Monterey Bay	4,769	Pajaro River	Streams	Gravity	Watsonville Water and Light Co.	do	200	Sanitary	Tide water.
Watts	Los Angeles River.	a 3,000	Los Angeles River.	Wells	Pumping	Conservative Realty Co.	do		None	
Whittier	San Gabriel River.	2,495	Coyote Creek	do	do	Municipal	do	No data.	do	
Wilmington	Los Angeles River.	1,200	Pacific Ocean	do	do	San Pedro Water Co.	do		do	

a Estimates by city or town clerk or by health officer; in some cases by Walton Van Winkle from the aforementioned. All others estimated for 1909 from United States Census, 1890 and 1900.

b Census of 1905, Blue Book of California.

INTERIOR BASIN AND COLORADO RIVER DRAINAGE.

DESCRIPTION.

The interior basin of California comprises that portion of the State lying east of the Sierra. It extends the whole length of the State as a narrow strip running from the northeastern corner and widening out in the southern part to include the great Mohave Desert. Its extreme southeastern boundaries are the low-lying hills that separate it from the drainage basin of Colorado River, and its southern limits are the mountains that shut it off from the Imperial Valley and the Salton Sea drainage.

Included in this drainage area are two principal subdrainages, the Sierra and the minor Great Basin. The first includes the Honey Lake drainage, of which the chief river is the Susan; the Truckee River drainage in California; the Mono Lake drainage; and the Owens River system. In the second is the Mohave River system.

The predominating surface formation of the northern part of the interior basin drainage is made up of tuffs and lavas. The middle section takes its geologic character from the Sierra Nevada and its surface rocks are largely granites. The lower portion, comprising the Mohave Desert, is a wide plateau interspersed with bare, soilless buttes of granite. The desert floor is a coarse, undecomposed granite sand, and in places the surface is coated with alkali dust.

The soils of the upper and middle portions of the drainage area are rich and fertile, only the high Sierra being bare of covering. The soil of the lower portion, although intrinsically rich, has in most places suffered so greatly from the extreme aridity of the climate that large deposits of alkaline and saline material lie on the surface, rendering it unfit for use even should it be possible to bring water upon it. In restricted areas north of the San Bernardino Mountains, where it has been possible to obtain artesian water, the desert is being slowly converted into a more or less fertile plateau, but it will be impracticable to reclaim a very large amount of land as the available water supply is extremely small.

In the Honey Lake and Truckee districts forestation is good, most of the timber being on government reserve. The greater part of the drainage area, that lying to the south of Owens Lake, is bare of trees, only here and there a dwarfed and stunted growth being found.

Except in the Honey Lake district and in Owens Valley the population is very small, and much of the basin supports only straggling mining camps. The total number of inhabitants may be estimated roughly at 150,000.

Grazing and agriculture are the principal industries in the Honey Lake region and in Owens Valley, while other parts of the area are

either without industries of any kind or are devoted chiefly to mining. The largest borax mines in the United States are in this region. Gold is mined at a number of places, and some sections of the desert yield materials suitable for the manufacture of cement.

The Colorado River drainage in California is small and unimportant and a general investigation of its waters was not attempted. Some analyses of the waters of Salton Sea are given on page 125.

SIERRA SUBDRAINAGE.

OWENS RIVER.

DESCRIPTION.

Owens River rises in the eastern slopes of the Sierra Nevada near San Joaquin Pass, at an elevation of over 10,000 feet above sea level, and about 90 miles from its source discharges into Owens Lake. Its course lies down the steep granite slopes of the Sierra, across the swampy meadow lands of Long Valley, and through a long canyon 800 feet deep, from which it finally emerges into Owens Valley proper. Passing eastward from the mouth of the canyon, it is deflected southward by the slopes of the White Mountains and flows slightly southeastward for the remainder of its course. Numerous tributary streams enter the valley, among which may be mentioned Rock, Pine, Bishops, Big Pine, Taboose, Oak, Independence, Shepherds, Georges, Long Pine, and Cottonwood creeks. All of these are relatively unimportant.

The drainage basin of Owens River is about 150 miles long and 20 to 25 miles wide.[a] It is bordered on the west by the Sierra Nevada, from which comes practically all the flow of its tributary streams, and on the east by the White Mountains, whose slopes, except in times of exceptional rainfall, are arid. The bed rock throughout all this basin is granite and the soil covering, except in the valley itself, is slight. Stock raising is the principal industry, but large areas are devoted to raising hay and grain.

The city of Los Angeles is building an aqueduct to take water from Owens River for its municipal supply, transporting it by siphon, flume, tunnel, and canal down Owens Valley, across the Mohave Desert, and through the San Fernando Mountains to the city.

Sampling stations were maintained on Owens River during 1908 at Round Valley and at Charlies Butte.

CHARACTER OF WATER AT ROUND VALLEY.

At Round Valley Owens River passes through a lava formation in a deep, rocky gorge. The bed of the stream is composed of rock and lava bowlders and the grade is sufficiently steep to cause a swift current.

[a] Clapp, W. B., Surface water supply of California, 1906: Water-Supply Paper U. S. Geol. Survey No. 213, 1907, p. 34.

Samples of water were taken from the river at Round Valley daily from April 12, 1908, to the end of the year by L. Roberts.

Stream flow in upper Owens River reaches its maximum in summer, when the snows on the mountains are melting. During the winter the run-off is small.

The series of analyses of the water of Owens River at Round Valley is incomplete, and it is therefore impossible to form a conception of seasonal variations as exact as might be desired. The water is alkaline carbonated in type, being unusual among California surface waters in this respect. The analyses show that the amount of dissolved mineral matter varies greatly during the year, falling below 100 parts per million when the snows are melting and increasing to more than 275 parts per million during the dry period, the increase being chiefly in the alkalies and the acid radicles.

The water is good for municipal use, its hardness being largely temporary. The addition of small quantities of soda ash will prevent the formation of scale from calcic and magnesic salts. The water is also well adapted for irrigation.

Mineral analyses of water from Owens River near Round Valley.

[Parts per million unless otherwise stated.]

Date.		Turbidity.	Suspended matter.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.	Mean discharge.	
From—	To—														Acre-feet per day.	Cubic feet per second.
1907. Dec. 31	1908. Jan. 9	15	10	48	0.05	17	4.5	53	0.0	144	35	1.2	23	270	494.1	249.2
1908. Jan. 10	Jan. 19	10	...	50	.05	17	4.1	63	[a]3.8	159	34	1.3	27	277	432.8	218.2
Jan. 20	Jan. 29	5	...	49	.05	23	5.7	58	.0	155	37	1.1	26	264	469.1	236.5
Jan. 30	Feb. 8	8	...	53	.55	18	4.5	68	.0	155	30	.66	28	268	445.5	224.6
Feb. 9	Feb. 18	5	...	29	.07	11	2.6	21	.0	63	21	.43	4.4	107	418.5	211
Apr. 9	Apr. 18	5	...	49	.15	16	5.2	56	.0	134	45	2.1	23	240	459.0	231.4
Apr. 19	Apr. 28	10	...	55	.15	13	3.8	47	.0	131	41	1.8	21	240	530.0	267.2
Apr. 29	May 4	4	...	53	.14	16	3.0	47	.0	124	30	1.9	22	216	560.7	282.7
May 9	May 18	4	....	48	.36	17	2.1	44	.0	131	31	.....	23	216	516.7	260.5
May 19	May 28	4	....	44	.18	16	3.1	46	.0	126	38	2.3	20	224	553.7	279.2
May 29	June 7	8	....	43	.15	14	4.0	41	.0	115	30	1.8	18	202	581.9	293.4
June 18	June 27	30	41	33	.95	15	4.4	35	.0	94	29	2.0	14	170	619.7	312.5
June 28	July 7	10	....	28	.30	14	7.3	20	.0	68	38	.34	8.5	135	593.2	299.1
July 8	July 17	Tr.	....	30	.08	14	4.2	29	.0	85	19	2.8	15	152	608.3	306.7
July 18	July 27	6	....	29	.19	15	4.5	24	.0	79	23	1.6	9.5	137	526.6	265.5
July 28	Aug. 6	20	60	32	.32	16	3.1	31	.0	93	19	.4	12	151	604.3	304.7
Aug. 7	Aug. 16	10	14	26	.28	13	3.1	15	.0	75	14	1.7	9.0	117	554.7	279.7
Aug. 17	Aug. 26	Tr.	....	25	.13	11	1.7	12	.0	59	15	.....	6.5	95	469.1	236.5
Aug. 27	Sept. 5	8	....	36	.40	18	2.3	21	.0	84	26	.2	7.7	142	458.2	231
Sept. 6	Sept. 15	10	....	32	.32	13	2.3	17	.0	78	18	.....	6.8	123	469.1	236.5
Sept. 26	Oct. 5	10	...	38	.16	12	4.0	31	.0	95	29	1.1	9.9	125	393.9	198.6
Oct. 6	Oct. 15	Tr.	....	35	.04	12	3.3	38	.0	92	38	.96	16	158	379.0	191.1
Oct. 27	Nov. 14	Tr.	....	23	.26	12	3.0	20	.0	62	23	.50	6.0	99	373.5	188.3
Nov. 16	Nov. 24	Tr.	....	23	.14	8.8	5.1	19	.0	73	12	1.0	2.0	116	362.8	182.9
Nov. 25	Dec. 4	Tr.	....	53	.08	15	5.7	64	.0	161	33	.88	29	271	362.8	182.9
Dec. 5	Dec. 14	Tr.	....	53	.04	14	8.7	66	.0	154	41	.40	28	264	368.2	185.7
Dec. 15	Dec. 24	Tr.	....	54	.06	15	10	54	.0	139	42	.42	22	236	353.0	178.0
Dec. 25	Dec. 31	8	....	45	.04	18	5.9	77	.0	164	40	.48	29	278	361.0	182.0
Mean		7	....	40	.20	15	4.3	40	.0	111	30	1.2	17	189	476	240
Per cent of anhydrous residue		....	....	19.7	0.1	7.4	2.1	19.7	27.2	.....	14.8	.6	8.4	.....	.....	.....

[a] Abnormal. Computed as HCO_3 in the average.

CHARACTER OF WATER AT CHARLIES BUTTE.

The intake for the diversion canal of the Los Angeles aqueduct is located near Charlies Butte, a basaltic mass in Owens Valley about 7 miles south of Tinemaha.[a] Samples of water were collected daily during 1908 from Owens River at this point by Ray Bowers.

At Charlies Butte the maximum flow occurs in the winter, the lower valley receiving considerable runoff from the rains and melting snows of the rainy season. A second period of high flow, resulting from the melting snows on the Sierra Nevada, occurs in the summer. In 1908 the summer flood was considerably less in volume than that of the winter, but showed a very decided increase over the ordinary dry-season discharge.

Fluctuation in the mineral content of Owens River is less and the total content is persistently greater at Charlies Butte than at Round Valley. Minimum values occurred in 1908 in October, when 203 parts per million were recorded, and maximum values—432 parts per million—were reached in the early spring.

The water is alkaline carbonated in type, as at Round Valley, the percentage composition of the samples from the two places being similar in this respect. Silica is high in value, while calcium and magnesium are relatively low.

The water is well adapted for irrigation and is suitable for a municipal supply, the chief hardness being of the temporary type. Small amounts of soda ash should be added before using this water in steam boilers. It is not particularly well adapted for the greater number of manufacturing industries which use water in connection with chemical processes.

[a] See Water-Supply Paper U. S. Geol. Survey No. 177, p. 83; also No. 213, p. 37.

Mineral analyses of water from Owens River at Charlies Butte near Tinemaha.

[Parts per million unless otherwise stated.]

Date.		Turbidity.	Suspended matter.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.	Mean discharge.	
From—	To—														Acre-feet per day.	Cubic feet per second.
1907. Dec. 31	1908. Jan. 9	10	....	44	0.15	28	7.4	66	0.0	171	46	1.0	27	290	1,017.5	513
1908																
Jan. 10	Jan. 19	20	....	44	.15	32	5.8	53	.0	167	49	1.4	29	288	1,035.5	522.1
Jan. 20	Jan. 29	20	36	45	.15	33	8.6	67	.0	199	63	1.7	36	362	1,127.2	568.3
Jan. 30	Feb. 8	30	79	43	.21	33	8.3	102	.0	233	73	1.4	49	407	1,288.4	649.6
Feb. 9	Feb. 18	20	38	42	.12	26	8.6	95	.0	212	65	1.5	43	366	1,106.2	557.7
Feb. 19	Feb. 28	30	57	42	.17	31	8.5	87	.0	216	63	5.7	41	374	1,095.8	552.5
Feb. 29	Mar. 9	18	....	43	.17	26	7.2	84	.0	211	50	2.5	39	344	989.2	498.7
Mar. 10	Mar. 19	25	87	47	.33	25	5.6	84	.0	205	51	3.2	39	353	1,108.9	559.1
Mar. 20	Mar. 29	35	79	43	.15	28	6.2	77	.0	218	45	3.0	34	338	878.3	442.8
Mar. 30	Apr. 8	10	....	48	.13	28	12	62	a 4.8	193	55	2.0	30	329	464.7	234.3
Apr. 19	Apr. 28	Tr.	....	45	.04	37	18	64	.0	272	63	.75	40	412	180.7	91.1
Apr. 29	May 8	5	....	42	1.0	41	22	79	.0	290	68	2.5	45	432	120.0	60.5
May 9	May 18	Tr.	....	43	.18	41	21	74	a 31	203	73	1.4	35	431	114.0	57.5
May 19	May 28	Tr.	....	41	.45	39	19	72	.0	266	67	2.1	40	396	115.0	58.0
May 29	June 7	Tr.	....	40	.15	38	19	70	.0	254	61	2.2	38	374	119.0	60.0
June 8	June 17	8	....	42	.13	39	20	72	.0	261	56	3.0	42	391	90.2	45.5
June 18	June 27	10	14	31	.18	37	14	68	.0	240	60	1.4	31	364	122.2	61.6
June 28	July 7	20	23	47	.33	32	20	79	a 2.4	249	53	.92	40	380	222.7	112.3
July 8	July 17	Tr.	....	41	.40	27	11	59	.0	188	41	.44	27	295	521.8	263.1
July 18	July 27	12	20	47	.13	32	16	55	a 6.0	212	45	1.1	30	331	323.8	163.3
July 28	Aug. 6	40	48	43	.08	26	11	51	.0	181	46	1.8	23	293	564.3	284.5
Aug. 7	Aug. 16	40	87	39	.30	28	8.5	49	.0	161	44	1.6	19	252	808.3	407.5
Aug. 17	Aug. 26	....	....	47	.55	32	11	51	a Tr.	195	43	1.0	14	302	320.5	161.6
Aug. 27	Sept. 5	8	....	39	.20	44	12	55	.0	210	48	2.0	27	317	213.2	107.5
Sept. 6	Sept. 15	50	30	40	.25	33	12	73	.0	222	49	1.8	37	351	272.3	137.3
Sept. 16	Sept. 25	20	28	41	.20	30	10	56	.0	196	45	.....	29	379	398.4	209
Sept. 26	Oct. 5	10	....	30	.04	30	10	58	.0	202	43	.54	27	307	494.1	249.1
Oct. 6	Oct. 15	20	25	40	.05	27	7.7	62	.0	195	39	.78	25	284	507.0	255.6
Oct. 16	Oct. 25	25	40	49	.13	25	9.0	64	.0	188	52	.74	25	303	632.9	319.1
Oct. 26	Nov. 4	15	....	41	.26	26	7.9	57	.0	171	42	.70	24	273	768.6	387.5
Nov. 5	Nov. 14	20	35	43	.07	27	8.4	60	.0	173	41	.20	24	278	788.8	397.7
Nov. 15	Nov. 24	8	....	55	.34	28	8.8	70	.0	188	56	1.1	26	314	786.6	396.6
Nov. 25	Dec. 4	14	14	42	.08	29	9.1	76	.0	188	69	3.3	35	334	808.3	407.5
Dec. 5	Dec. 14	14	17	46	.36	30	11	81	.0	185	67	1.6	36	344	865.2	436.2
Dec. 15	Dec. 24	Tr.	....	45	.34	28	9.9	64	.0	189	48	3.8	30	310	748.7	377.5
Dec. 25	Dec. 31	10	....	46	.08	27	9.8	86	.0	190	79	.70	34	312	799.2	402.9
Mean		16	....	43	.22	31	12	69	.0	211	54	1.7	33	339	606	306
Per cent of anhydrous residue		....	....	12.4	0.1	8.9	3.4	19.8	29.9	.....	15.5	0.5	9.5	.....	.....	.....

a Abnormal. Computed as HCO_3 in the average.

OWENS LAKE.

DESCRIPTION.

Owens Lake, into which the waters of Owens River discharge, is a large, shallow body of water lying in the southern extremity of Owens Valley. The lake is without visible outlet, and its volume depends on the relation of inflow to evaporation. The general tendency of the lake toward gradual diminution in size has recently been checked by a succession of unusually wet seasons, which have sent abnormally large quantities of water to the lake. The summer droughts have failed to restore the water to its ordinary level, and, temporarily at least, the size of the lake is increasing. On May 1, 1909, the water level was higher than it had been for many years.

CHARACTER OF WATER.

The lake shows every evidence of having been at one time a body of pure, fresh water, but owing to its landlocked condition and to the resultant gradual concentration of the salts held in solution it is now one of the most strongly saline lakes in America. It has been of great interest to chemists and its waters have several times been analyzed. Oscar Loew estimated that in 1876 it contained 22,000,000 tons of sodium carbonate and 5,000,000 tons of potassium sulphate in solution.[a] At the time of his analysis it was not known that the water contained large amounts of borates, and only traces of these were recorded by him. Later, in 1886, T. M. Chatard made analyses of samples collected by I. C. Russell, of the United States Geological Survey, and his report[b] indicates a large amount of boric acid in solution. He, however, neglected to find any considerable amount of phosphoric acid, arsenic, or nitric acid, and his analyses can not therefore be considered complete. In 1906, at the request of Willis T. Lee, one of the geologists of the Survey, a complete analysis of the waters of the lake was made by C. H. Stone and F. M. Eaton. The results of the various analyses here referred to are presented in the following table:

Analyses of the water of Owens Lake.

[Parts per million.]

	1.	2.	3.
Silica (SiO_2)	164	207	297
Iron (Fe)		9.2	(as Al) 48
Aluminum (Al)	Trace.	12	
Calcium (Ca)	Trace.	13	34
Magnesium (Mg)	Trace.	4.7	15
Lithium (Li)	Trace.		57
Sodium (Na)	21,652	26,836	81,176
Potassium (K)	2,751	1,548	3,448
Carbonate radicle (CO_3)	13,146	18,265	52,326
Sulphate radicle (SO_4)	9,362	7,067	21,174
Chlorine (Cl)	13,444	18,214	52,898
Phosphate radicle (PO_4)	Trace.		238
Borate radicle (B_4O_7)	Trace.	346	296
Hydrogen (H)		59	130
Nitrate radicle (NO_3)	Trace.		948
Organic matter	Trace.		
Cæsium (Cs)			Trace.
Rubidium (Rb)			Trace.
Arsenic (As)			84
Total solids	60,430	72,471	213,661
Specific gravity	1.051	[a] 1.062	1.1954

[a] At 25° C.
1. Analysis by Doctor Loew, 1876.
2. Analysis by T. M. Chatard, 1886.
3. Analysis by C. H. Stone and F. M. Eaton, 1906.

The analyses show that the alkaline carbonates, chlorides, and sulphates form the greater part of the dissolved mineral matter, the sulphates being important because they are most troublesome in the manufacture of soda. Nitrates, phosphates, and arsenic, as reported

[a] Ann. Rept. U. S. Geog. Surveys W. 100th Mer., 1876, App. H3, p. 193.
[b] Chatard, T. M., Natural soda, its occurrence and utilization: Bull. U. S. Geol. Survey No. 60, 1886, p. 58.

in the analysis by Stone and Eaton, are present in greater quantities than have been elsewhere reported for surface waters.

The water is used commercially for the recovery of soda, and a large plant is situated on the shores of the lake at Kieler. This soda plant and the Death Valley borax plant form the two notable manufactories of eastern California, and the water of Owens Lake must therefore be ranked as one of the most important natural commercial assets of the region.

MONO LAKE.

Mono Lake lies in an elevated valley directly north of the headwaters of Owens River. It receives a scant drainage from the surrounding mountains, and, having no outlet, maintains its level by means of evaporation. An analysis of the water of this lake, made in 1882 by T. M. Chatard[a] is quoted here for comparison with the analyses of the water of Owens Lake.

Analysis of water of Mono Lake.[b]

[Analyst, T. M. Chatard.]

	Parts per million.		Parts per million.
Silica (SiO_2)	67	Carbonate radicle (CO_3)	13,101
Aluminum (Al)	1.5	Sulphate radicle (SO_4)	6,384
Iron (Fe)		Borate radicle (B_4O_7)	153
Calcium (Ca)	19	Chlorine (Cl)	11,581
Magnesium (Mg)	53	Hydrogen (H)	50
Sodium (Na)	18,837	Total solids	51,170
Potassium (K)	920		

The analysis shows that this water, like that of Owens Lake, contains chiefly alkaline carbonates, chlorides, and sulphates, but that it is less concentrated than the water of Owens Lake. Owing to its elevation and to the resulting brief duration of the warm season it is doubtful whether this lake can be developed commercially.

LAKE TAHOE.

Lake Tahoe is situated in the high Sierra region in the east-central part of California, and is the first of a series of lakes in California and Nevada connected by the Truckee and Carson rivers. It lies at a great elevation and derives its water chiefly from the melted snows of the Sierra Nevada. The following analysis, by F. W. Clarke,[c] shows the marked freedom of the water of this lake from mineral matter in solution.

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[a] Chatard, T. M., Natural soda, its occurrence and utilization: Bull. U. S. Geol. Survey No. 60, 1887, p. 53.

[b] Sample collected in 1882 by I. C. Russell on east side of lake at a depth of 1 foot.

[c] Clarke, F. W., The data of geochemistry: Bull. U. S. Geol. Survey No. 330, 1908, p. 122.

Analysis of water of Lake Tahoe.

[Analyst, F. W. Clarke.]

	Parts per million.		Parts per million.
Silica (SiO_2)	14	Carbonate radicle (CO_3)	28
Calcium (Ca)	9.4	Sulphate radicle (SO_4)	5.5
Magnesium (Mg)	3.0	Chlorine (Cl)	2.3
Sodium (Na)	7.4	Total solids	73
Potassium (K)	3.3		

From the above analysis it is apparent that the water is alkaline carbonate in type, similar to that of Owens River. It is of great mineral purity and could be used for any purpose without previous treatment, except that for domestic use its general bacterial purification is necessary.

MINOR GREAT BASIN SUBDRAINAGE.

MOHAVE RIVER.

DESCRIPTION.

Mohave River rises on the northern slopes of the San Bernardino Mountains, flows through high valleys in a general northerly direction to a point near Oro Grande, where it turns eastward and gradually loses itself in the sandy Mohave Desert. Few streams are tributary to this river and all of these join it in its mountain reaches. The bed rock at the headwaters is granitic, with a good soil covering, and this condition continues, except for occasional beds of limestone, throughout the entire course of the stream. The floor of Mohave Desert is composed of a disintegrated granite sand rich in feldspar, permitting the solution of large quantities of alkaline minerals.

The upper valley of the Mohave, between the San Bernardino Mountains and Victorville, receives no surface flow except in the winter months. At Victorville a granite ledge forms a barrier to the passage of the underflow, and the river rises to the surface through what is locally called the "Narrows." Northward from the "Narrows" the valley gradually broadens out and the river again sinks slowly into its sandy bed. The lower course of the stream in the desert is marked by a decided efflorescence of alkaline material, and it is probable that the waters here are very heavily impregnated.

CHARACTER OF WATER.

A single sample of water was taken from the Mohave at Victorville on March 17, 1908. At this place, at which it has been proposed to erect a dam to impound water for irrigation, the river bottom is rocky, with large stretches of shifting sand, and the current is swift. The results of the analysis are shown in the following table:

Analysis of water of Mohave River at Victorville, March 17, 1908.

[Analyst, Walton Van Winkle.]

	Parts per million.		Parts per million.
Turbidity	15	Carbonate radicle (CO_3)	.0
Silica (SiO_2)	25	Bicarbonate radicle (HCO_3)	83
Iron (Fe)	.20	Sulphate radicle (SO_4)	7.9
Calcium (Ca)	15	Chlorine (Cl)	6
Magnesium (Mg)	2.9	Nitrate radicle (NO_3)	.36
Sodium and potassium (Na+K)	15	Total solids	117

So far as may be judged from a single analysis, the water of Mohave River at the Narrows is of excellent quality. Total solids are low, hardness is small and chiefly temporary, and serious mineral contamination is not indicated. For use in boilers no treatment of the water is necessary. Soap consumption is small, and the water is admirably adapted for general purposes.

SALTON SEA.

As the Colorado River drainage in California is small and unimportant a general investigation of its waters was not attempted. For special purposes, however, analyses have been made of the waters of Salton Sea, the large, shallow body of water lying in a depression at the head of Imperial Valley in what was formerly called Salton Sink. Once an inland sea formed by the waters of the Colorado, it later lost its inlet through the silting up of the channel, and finally dried up into a saline bed or sink, and small streams flowing into it from the surrounding mountains lost themselves in its sandy wastes. In 1891 the high water in the Colorado overflowed into the sink, forming anew the Salton Sea. Flooding was renewed in 1905, increasing the size of the sea. Although the waters of Colorado River are now restrained from overflow into this valley, considerable seepage water and waste from the irrigating ditches still enters the sink, and as a result the evaporation of the sea will be a matter of many years.

In November, 1907, G. K. Gilbert obtained a sample of water from the sea, and in February, 1908, another sample was collected by J. A. Jeffrey. The first sample was analyzed in the laboratory at Berkeley; the later one was analyzed in the Survey laboratory, at Austin, Tex. The results of these analyses are presented in the following table:

Analyses of water of Salton Sea.

[Parts per million.]

	1.	2.		1.	2.
Turbidity	Trace.		Potassium (K)	150	155
Silica (SiO_2)	19	4	Carbonate radicle (CO_3)	12	11
Iron (Fe)	.08	.4	Bicarbonate radicle (HCO_3)	140	159
Aluminum (Al)		4.9	Sulphate radicle (SO_4)	559	562
Calcium (Ca)	107	142	Chlorine (Cl)	1,827	1,925
Magnesium (Mg)	68	77	Nitrate radicle (NO_3)	.35	
Sodium (Na)	1,123	1,190	Total solids	3,912	4,087

1. Collected November 12, 1907, by Dr. G. K. Gilbert, and analyzed by Walton Van Winkle.
2. Collected February 28, 1908, by J. A. Jeffrey, Mecca, Cal., and analyzed by J. A. Bailey and A. M. McAfee.

The water is alkaline muriated, as might be expected in a sink of this nature. It is useless for practical purposes, and the analyses serve merely to indicate the commencement of the gradual increase in concentration of minerals which will occur until the lake finally disappears.

NOTES ON MUNICIPALITIES.

But three incorporated towns in these drainage areas reported water-supply conditions. The statistics appear in the following table:

Statistics of municipal water supplies in interior basin and Colorado River drainage basin.

Settlement.	Drainage basin.	Population.	River.	Source of supply.	Nature of system.
Bishop	Owens River	2,000	Owens	Stream	Gravity.
Imperial	Colorado River	2,000	.....	Colorado River	Gravity and pumping.
Susanville	Honey Lake	1,000	Susan	Springs	Gravity.

Settlement.	Ownership.	Methods used for purification.	Per capita daily consumption (gallons).	Nature of sewerage system.	Ultimate disposal of sewage.
Bishop	Municipal	Sedimentation	No data.	Combined	Sewer farm.
Imperial	Imperial Land, Water and Power Co.[a]	Sedimentation and filtration.	75	None	
Susanville	Lassen Land, Water and Power Co.	None	No data.	Sanitary — septic tank.	

FEATURES INFLUENCING THE QUALITY OF THE SURFACE WATERS.

The amount of mineral matter in natural surface waters depends principally on, first, the nature and the texture of the geologic formations with which the water comes into contact; second, climatic conditions; and, third, amount of vegetation. Other factors, among which may be mentioned distance from the ocean, affect the mineral content to a less degree.

INFLUENCE OF GEOLOGIC FORMATIONS.

It can be seen from study of the table on page 127 that the rivers of the eastern portion of the State receive but little mineral matter from the resistant granite formations of the Sierra, while the coastal rivers, draining areas composed in large part of loose sedimentary deposits, show much higher mineral content. The amount of magnesium does not vary appreciably with difference in climatic condition, hence the variation in percentage composition of the mineral residues from the waters, due to difference in geologic formations, is well illustrated by this constituent. All rivers studied whose content of magnesium was above 6.5 per cent of the total anhydrous

residue flow over the sedimentary deposits and ferromagnesian eruptive rocks of the coast region.

The four rivers whose magnesium is below 4 per cent flow from granite formations, two from the southern portion of the Sierra, one from the San Bernardino Mountains, and one from the Santa Cruz Mountains. The lowest magnesium was found in the two streams from the Sierra—Kern and Owens rivers, Owens River averaging slightly less than Kern River. The low magnesium content in Santa Ana River at Corona is attributed to the effect of using the water to irrigate soil poorer in magnesium than the formations nearer the headwaters. The percentage of magnesium in solution at Mentone before the water is drawn out for irrigation is slightly greater. San Lorenzo River is the fourth river of low magnesium content, and like Kern and Owens rivers owes its small percentage to the granite formations over which it flows in its upper course.

Owing to other and greater variations in mineral content in the waters of California it is not proper to compare percentage compositions in studying silica values. A comparison of absolute quantities of silica present, however, indicates a relation between geologic structure and the amount of silica in the river waters. The following table shows the average values, in parts per million, of silica for the rivers studied. The rivers are arranged in order of geographic position, from north to south.

Silica (SiO_2) in California rivers.

[Parts per million.]

COASTAL RIVERS.		SIERRA RIVERS.	
Russian	19	Feather	16
Cache Creek	16	Yuba	14
Alameda Creek	19	American	17
San Lorenzo	23	Sacramento (1906)	19
San Benito	24	Sacramento (1908)	27
Arroyo Seco	26	Mokelumne	14
San Antonio	37	San Joaquin (1906)	16
Nacimiento	25	San Joaquin (1908)	19
Estrella	35	Stanislaus	14
Salinas	31	Tuolumne	11
Santa Maria	24	Merced	14
Santa Ynez (1906)	24	Kern	18
Santa Ynez (1908)	22	Owens, Round Valley	40
Ventura	23	Owens, Charlies Butte	43
Malibu Creek	36		
San Gabriel, Azusa	21		
San Gabriel, Rivera	23		
Santa Ana, Corona	31		
Santa Ana, Mentone (1906)	16		
Santa Ana, Mentone (1908)	25		
San Luis Rey	31		
Santa Ysabel	44		
Cottonwood Creek	44		

The silica content in the coastal rivers increases with considerable regularity from north to south, slight irregularities being occasioned by some high values in the Salinas River system and in Malibu Creek. This tendency to a regular increase is not noticeable in the Sierra rivers, in which the amount of silica varies but slightly, except in Owens River, on the southeast side of the Sierra, which has, however, a silica content about three times as great as that of the streams on the western slope. Near the coast and in the central arid regions the influence of vegetation is overshadowed by the greater effect of geologic conditions, but on the western slope of the Sierra the effects of vegetation mask those of rock composition. The rock formations in California are, broadly speaking, basic in the northern portions, increasing in acidity toward the south. North of San Francisco Bay the basic character is pronounced, in the sedimentary rocks of the Gabilan Range a more acidic nature is manifest, and in the mountains of the southwest corner of the State the formations are markedly acidic. A slightly more basic character is noticeable in the formations of the valley of southern California and of its mountain girdle and in those of the Santa Ynez Range. The table of silica values shows a change in amount of silica dissolved in the river waters for each corresponding change in basicity of the rock formations and the analyses of the "spot" samples scattered through the report give further evidence of this close relation.

INFLUENCE OF CLIMATIC CONDITIONS.

Climatic conditions, through their influence on the quantity of vegetation, have important effect on the quality of water. There is no distinct division between regions of abundant and those of deficient rainfall in California, and for purposes of comparison an arbitrary line of division must be selected. In the present work a lower limit of 15 inches of rainfall annually has been chosen for humid regions, and all areas showing in general a less amount have been classed as semiarid, because it appears from study of the rainfall map of California,[a] that those regions of California commonly called semiarid receive average annual rainfalls of less than 15 inches, and that the maximum for such areas seldom exceeds that figure. The average precipitation for each catchment area was then roughly determined from the rainfall map, particular emphasis being placed on the rainfall of the headwater regions, as this furnishes the greater portion of the run-off of the California streams. The rivers were thus classified under the two heads, humid and semiarid.

Although the classification so obtained is crude, it serves to indicate several points of importance regarding rivers in California. First, the average mineral content of waters in semiarid regions is, roughly, four

[a] McAdie, A. G., Climatology of California, U. S. Weather Bureau Bull. L, 1903, Chart VIII.

times that of waters in humid regions. Second, differences in percentage composition of the anhydrous residues show that the waters in semiarid regions contain about two-thirds the proportionate amount of silica, less calcium, four-fifths as much carbonates, and twice as much sulphates, as the waters of the humid regions. Other constituents are similar in amount. In regions of abundant rainfall disintegration of rock material can not keep pace with solution, erosion, and chemical decomposition. The more soluble constituents of the rocks are rapidly removed as they become exposed to the action of water, and their total amount in a given quantity of the solvent water is seldom great. In arid or semiarid regions, however, chemical action is frequently less marked than physical disintegration. The soluble materials of the disintegrated rock masses accumulate through periods of drought, allowing the water from subsequent rainfalls to take into solution a greater relative amount than is found in waters from the more humid regions.

In the waters studied the average amount of mineral in streams from the semiarid regions was 627 parts per million; in rivers of the humid regions it was 165 parts per million. The greatest average mineral content, 2,412 parts per million, occurred in Santa Maria River, which flows through a sandstone country receiving barely 10 inches of rain a year. The smallest amount of mineral matter was found in Merced River, 65 parts per million, or about one-fortieth of the amount for Santa Maria River. Merced River drains a granite country receiving in its upper portions over 45 inches of rain annually. The greatest individual determination of total solids was in water of San Lorenzo Creek, in the semiarid Salinas Valley, 3,689 parts per million on April 7, 1908. The smallest, 30 parts per million, was in Mokelumne River, June 21 to 30, 1906, when that river was receiving a large amount of water from the melting snows on the Sierra slopes, as well as from the spring rains.

As the silica content is apparently unaffected by the amount of the other dissolved constituents, it may be expected that the percentage of silica in rivers of high dissolved solids will be correspondingly low. This is true in California waters, the average silica for the humid-region rivers being 13.4 per cent and for the semiarid-region waters 8.0 per cent of the total mineral matter in solution. The principal effect, then, of climatic condition on silica content is a negative one and it is apparently due merely to change in total mineral content.

By the decay of the abundant organic material in humid regions carbonic acid is set free, being dissolved in the surface waters or entering the air as carbon dioxide. This carbonic acid, uniting with the carbonic acid of the alkaline-earth carbonates, produces the bicarbonates which are readily dissolved, so that surface waters in

regions of abundant rainfall, carry large amounts of the bicarbonate radicle and of the alkaline earths. In regions of deficient rainfall, on the other hand, carbonate rocks are attacked to less extent and the gypsum and alkaline sulphates that are present are brought more largely into solution.

In considering the foregoing comments on the mineral constituents of the waters, it must be borne in mind that simple conditions do not occur in any of the regions, but that the effect of a stated geologic or climatic condition may be completely masked by that of another, or may be increased beyond the normal by that of still another. The effect on one constituent may thus be so clouded by changes in others as to be indeterminate. Geologic conditions vary throughout the State, and are not in general similar for the arid and the humid regions. Gypsum, for example, is more abundant in the formations of the southern part of the State than in the northern portions or in the Sierra. Some rivers also show certain irregularities not due to natural causes, as, for example, Alameda Creek, the water of which is high in its mineral content because it receives an abnormal proportion of ground water on account of an obstruction to subsurface flow above the point of sampling. Such influences must be considered before any general conclusions are made.

INFLUENCE OF DISTANCE FROM THE OCEAN.

Distance from the sea affects the chlorine content of river waters by reason of the chlorine in finely divided salt spray that is carried inland with dust particles by the wind and precipitated with the rain. Therefore, within the limits of wind-carried salt the nearer a stream is to the sea the greater its chlorine content will be. In the northeastern United States determinations of this normal chlorine content have been made,[a] and such estimates have been valuable in sanitary studies of water supplies. In California, however, in most of the drainage basins studied, the chlorine derived from the atmosphere is completely masked by the much greater amount derived from saline deposits and from other chloride-bearing rocks. Therefore it is impracticable to locate lines of equal normal chlorine (isochlors) from present information regarding the quality of the waters.

SUMMARY.

The average mineral content of the 37 rivers studied in detail is 368 parts per million, the average in the humid regions being 165 parts and in the semiarid regions 628 parts. The bicarbonate radicle is predominant in most of the waters. Its place is taken by the sulphate radicle in the water from the regions of least rainfall. The

[a] Jackson, D. D., The normal distribution of chlorine in the natural waters of New York and New England: Water-Supply Paper U. S. Geol. Survey No. 144, 1905.

average amount of the bicarbonate radicle, computed as normal carbonate, is 27.3 per cent of the anhydrous residue, and the amount of this constituent is never abnormally high as compared with that found in surface waters of other sections of the United States; but in the waters of the more arid regions its relative amount sinks into insignificance, averaging only 5.8 per cent in Santa Maria River. The sulphate radicle fluctuates in inverse ratio to the bicarbonate radicle. It forms 58.5 per cent of the residue of the water from Santa Maria River, and in the humid regions it is as low as 10.2 per cent in the average of Santa Ana River at Mentone in 1906. In examination of the "spot" samples, the lowest carbonate and the highest sulphate percentages were found in the same stream, Gaviota Creek, where carbonates were only 3.1 per cent and sulphates were 60.3 per cent of the total anhydrous residue.

ECONOMIC VALUE OF THE WATERS.

The following table shows the average values of the waters examined with reference to their steaming qualities. The results obtained also serve to indicate the qualities of the waters for many other purposes, and may be assumed to indicate the economic value of the waters. The properties considered are the tendency to foam, to prime, and to cause corrosion, the amount of scale deposited by the water, and the nature of the scale. The method of study was that outlined by Stabler,[a] the suspended matter not being considered, it being assumed that this would be settled or filtered out if the water were to be put to industrial use. The values are averages for the period of examination, and figures are not given.

Under foaming the following classification was employed: Nonfoaming indicates that the water could be used for one week or more in a locomotive boiler without foaming; semifoaming, that it could be used for two days to one week under the same conditions without foaming; and foaming, that it would cause foaming in less than two days. Similarly, classification of the corrosive tendency is made as noncorrosive when there was no chemical evidence that corrosion of metals might occur; semicorrosive when certain conditions of its use might cause corrosion; and corrosive if a positive tendency to produce corrosion existed. Under scale, if not over 1 pound of scale would be deposited for each 1,000 gallons used, the water is classed as giving very little scale; if between 1 and 2 pounds of scale would be deposited per 1,000 gallons, the water is classed as producing little scale; if between 2 and 4 pounds of scale would result from its use, the water is classed as giving much scale; and if over 4 pounds of scale would

[a] Stabler, Herman, The mineral analysis of water for industrial purposes and its interpretation by the engineer: Eng. News, vol. 60, 1908, p. 356.

deposit on the use of 1,000 gallons of the water it is classed as depositing very much scale. The nature of the scale is described as soft, medium, or hard, according to the ratio of the hard scale to total scale formed, soft scale containing not over one-quarter of the total as hard scale, medium scale, not over one-half or under one-quarter, and hard scale not under one-half of the total scale as hard scale.

The industrial values of California surface waters.

Stream.	Priming	Corrosion.	Scale.	Nature of scale.	Nature of drainage basin.
Alameda Creek	Semifoaming	Semicorrosive	Much	Medium.	Humid.
American River	Nonfoaming	do	Very little	do	Do.
Arroyo Seco	Semifoaming	Noncorrosive	Little	do	Semiarid.
Cache Creek	do	do	Very little	Hard	Humid.
Cottonwood Creek	do	do	Much	Medium.	Semiarid.
Estrella River	Foaming	Semicorrosive	do	Hard	Do.
Feather River	Nonfoaming	do	Very little	Medium.	Humid.
Kern River	do	do	do	do	Do.
Malibu Creek	Semifoaming	do	Much	Hard	Semiarid.
Merced River	Nonfoaming	do	Very little	Medium.	Humid.
Mokelumne River	do	do	do	do	Do.
Nacimiento River	Semifoaming	do	Little	Hard	Semiarid.
Owens River, Charlies Butte	do	Noncorrosive	do	Medium.	Do.
Owens River, Round Valley	do	do	Much	Hard	Do.
Russian River	Nonfoaming	Semicorrosive	Very little	Medium.	Humid.
Sacramento River, 1906	do	do	do	do	Do.
Sacramento River, 1908	do	do	do	do	Do.
Salinas River	Semifoaming	do	Much	Hard	Semiarid.
San Antonio River	do	do	Little	Medium	Do.
San Benito River	Foaming	do	Much	do	Do.
San Gabriel River, Azusa	Nonfoaming	Noncorrosive	Little	Soft	Humid.
San Gabriel River, Rivera	do	do	do	do	Do.
San Joaquin River, 1906	Semifoaming	Semicorrosive	Very little	Hard	Do.
San Joaquin River, 1908	do	do	do	do	Do.
San Lorenzo River	do	do	Little	Medium.	Do.
San Luis Rey River	do	do	do	do	Semiarid.
Santa Ana River, Corona	do	Noncorrosive	Much	Soft	Humid.
Santa Ana River, Mentone, 1906	Nonfoaming	Semicorrosive	Very little	do	Do.
Santa Ana River, Mentone, 1908	do	Noncorrosive	do	Medium.	Do.
Santa Maria River	Foaming	Corrosive	Very much	Hard	Semiarid.
Santa Ynez River, 1906	Semifoaming	Semicorrosive	Much	do	Do.
Santa Ynez River, 1908	do	do	do	do	Do.
Santa Ysabel Creek	do	do	Little	Medium.	Do.
Stanislaus River	Nonfoaming	do	Very little	do	Humid.
Tuolumne River	do	do	do	do	Do.
Ventura River	Semifoaming	do	Much	Hard	Semiarid.
Yuba River	Nonfoaming	do	Very little	Medium.	Humid.

It is apparent from this classification that the surface waters of California are in general hard; that none of the semiarid region waters are of excellent quality for industrial purposes; that the Sierra rivers have a tendency to produce a small amount of hard scale in boilers; that the number of nonfoaming waters is small, but that the number of waters bad in this respect is less in the humid than in the semiarid region; and that the softest and best waters for steaming purposes are those in the orange belt of southern California.

The waters from the Gabilan and Diablo ranges and from Santa Maria River are classed as foaming. The Santa Maria furnishes the sole example of a corrosive water, though others, notably Estrella River, show strong tendency to cause corrosion under certain circumstances.

Owens River between Round Valley and Charlies Butte shows a change from a poor water depositing much hard scale in boilers to a far better water producing but little medium scale. This is the result of inflow of softer, less strongly mineralized water between the points of collection.

The marked differences in the quantity of mineral matter in the waters, from analysis to analysis, and in the averages for each of the two years, where work was done in both 1906 and 1908, show how important it is for the engineer or chemist to have data covering a long period of time before he can correctly determine the most suitable means of treating these waters for industrial use. Analyses made from single samples of any of the rivers studied would have given decidedly erroneous ideas of the quality of the water and the limits of mineral content which it might be expected to reach.

SUMMARIES.

In conclusion are presented three tables giving in summary form the results of the analyses recorded in this report.

Summary of results of mineral analyses of surface waters of California.

Source of sample.	Average mineral content (parts per million).												Chemical composition of mineral matter (per cent of anhydrous residue).							
	Turbidity.	Suspended matter.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).
Alameda Creek, Niles	.....	163	19	0.13	66	28	49	4.4	262	91	.....	34	421	4.5	0.0	15.7	6.6	11.7	31.8	21.6	....	8.1
American, Fairoaks	.....	146	17	.39	11	4.4	11	.0	41	12	.....	6.3	83	20.7	.5	13.4	5.3	13.4	24.4	14.6	....	7.7
Arroyo Seco, Soledad	.....	33	26	.20	51	14	29	.0	170	72	.....	13	284	9.0	.1	17.6	4.9	10.0	29.0	24.9	....	4.5
Cache Creek, Yolo	64	.....	16	.19	30	23	33	2.1	193	28	1.3	31	250	6.2	.1	11.6	8.9	12.7	37.6	10.7	0.5	11.7
Cottonwood Creek, Barrett dam	19	.....	44	.18	51	20	69	3.7	246	52	1.0	62	413	10.4	.0	12.0	4.7	16.3	29.5	12.3	.2	14.6
Estrella, San Miguel	161	.....	35	.19	79	53	224	9.6	273	385	.88	192	1,131	3.1	.0	7.1	4.8	20.1	12.9	34.6	.1	17.3
Feather, Oroville	.....	41	16	.17	13	5.7	14	.0	64	11	.....	5.8	99	16.4	.2	13.3	5.8	14.3	32.8	11.3	....	5.9
Kern, Bakersfield	.....	163	18	.15	18	4.2	22	.0	71	21	.....	9.1	127	14.1	.1	14.1	3.3	17.3	27.5	16.5	....	7.1
Malibu Creek, Calabasas	.....	61	36	.11	101	50	73	2.2	288	285	.....	42	751	4.9	.0	13.8	6.8	10.0	19.7	39.0	....	5.8
Merced, Merced Falls	.....	52	14	.10	9.1	3.8	9.3	.0	35	11	.....	5.6	65	20.0	.2	13.0	5.4	13.3	24.3	15.8	....	8.0
Mokelumne, Clements	.....	84	14	.18	12	3.8	13	.0	42	12	.....	7.3	75	16.8	.2	14.4	4.6	15.6	25.2	14.4	....	8.8
Nacimiento, San Miguel	36	.....	25	.19	42	22	24	1.7	171	72	4.4	14	286	8.6	.1	14.5	7.6	8.3	29.8	24.8	1.5	4.8
Owens:																						
Charlies Butte	16	.....	43	.22	31	12	69	.0	211	54	1.7	33	339	12.4	.1	8.9	3.4	19.8	29.9	15.5	.5	9.5
Round Valley	7	.....	40	.20	15	4.3	40	.0	111	30	1.2	17	189	19.7	.1	7.4	2.1	19.7	27.2	14.8	.6	8.4
Russian, Ukiah	9	.....	19	.19	23	12	16	.0	125	17	1.2	7.4	145	12.0	.1	14.6	7.6	10.1	39.4	10.8	.8	4.6
Sacramento, above Sacramento (1906)	.....	60	19	.29	15	7.0	15	.0	76	13	.....	8.7	124	16.6	.2	13.0	6.1	13.0	32.2	11.3	....	7.6
Sacramento, above Sacramento (1908)	66	102	28	.43	13	6.7	13	.0	74	17	.64	5.4	113	23.2	.4	10.8	5.6	10.8	30.0	14.1	.5	4.6
Salinas, Paso Robles	16	.....	31	.15	60	28	59	5.6	272	97	.74	39	448	6.8	.0	13.2	6.2	13.0	30.7	21.3	.2	8.6
San Antonio, Bradley	10	.....	37	.16	63	21	38	2.5	224	94	1.0	24	387	9.5	.0	16.1	5.4	9.7	28.9	24.0	.3	6.1
San Benito, Hollister	.....	1,444	24	.09	58	57	110	6.2	335	204	.....	95	732	3.3	.0	8.1	8.0	15.3	23.8	28.3	....	13.2
San Gabriel:																						
Azusa	23	.....	21	.16	45	12	18	3.3	176	32	1.1	4.3	208	9.4	.1	20.1	5.4	8.0	40.3	14.3	.5	1.9
Rivera	5	.....	23	.11	55	12	22	2.2	211	33	1.9	8.4	246	8.8	.1	21.0	4.6	8.4	40.6	12.6	.7	3.2
San Joaquin:																						
Lathrop (1906)	.....	60	16	.23	18	8.0	27	.0	66	26	.....	30	161	10.1	.1	11.4	5.1	17.1	20.9	16.4	....	18.9
Lathrop (1908)	34	52	19	.30	20	10	36	.0	74	39	1.0	47	205	9.1	.1	9.6	4.8	17.3	17.3	18.7	.5	22.6
San Lorenzo, Big Trees	.....	84	23	.18	44	10	31	.0	147	43	.....	29	255	9.1	.1	17.4	3.9	12.5	28.5	17.0	....	11.5
San Luis Rey, Pala	.....	142	31	.12	42	13	44	.0	163	53	.....	39	321	10.3	.0	13.9	4.3	14.6	26.5	17.5	....	12.9
Santa Ana:																						
Corona	65	.....	31	.18	61	13	49	3.7	233	42	2.3	41	347	8.7	.0	17.1	3.6	13.8	33.0	11.7	.6	11.5
Mentone (1906)	.....	55	16	.15	26	5.7	18	.0	102	14	.....	7.3	158	11.7	.1	19.0	4.2	13.1	36.4	10.2	....	5.3
Mentone (1908)	8	.....	25	.16	25	6.3	18	.0	116	20	.75	3.8	145	16.0	.1	16.0	4.0	11.6	36.6	12.8	.5	2.4
Santa Maria, Santa Maria	.....	1,302	24	.14	302	133	200	.0	254	1,253	.....	105	2,412	1.1	.0	14.1	6.2	9.4	5.8	58.5	....	4.9

Santa Ynez:																								
Santa Barbara (1906)		64	24	.11	101	45	58	2.6	265	287		25	714	3.6	.0	15.0	6.7	8.6	19.9	42.6		3.6
Santa Barbara (1908)[a]	32		22	.15	109	49	66	2.4	258	373	.46	14	785	2.9	.0	14.3	6.4	8.6	16.9	49.0	.1	1.8
Santa Ysabel, San Pasqual	14		44	.17	29	13	42	1.3	160	30	.84	38	260	16.0	.1	10.5	4.7	15.3	28.4	10.9	.3	13.8
Stanislaus, Knights Ferry		140	14	.20	11	5.0	11	.0	46	11		5.6	83	17.3	.3	13.6	6.2	13.6	28.5	13.6		6.9
Tuolumne, La Grange		68	11	.19	10	4.3	12	.0	41	12		6.6	74	14.4	.2	13.1	5.6	15.8	26.3	15.8		8.8
Ventura, Ventura	3		23	.14	106	30	47	3.9	226	251	.72	20	605	3.9	.0	17.9	5.1	7.9	19.4	42.4	.0	3.4
Yuba, Smartsville	191		14	.21	13	4.3	10	.0	48	13		5.5	84	16.7	.2	15.5	5.1	11.9	28.6	15.5		6.5

[a] Part of year only.

Summary of results of analyses of surface waters of California from drainage areas receiving 15 inches or more annual rainfall.

Source of sample.	Average mineral content (parts per million).													Chemical composition of mineral matter (per cent of anhydrous residue).							
	Turbidity.	Suspended matter.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).
Alameda Creek, Niles		163	19	0.13	66	28	49	4.4	262	91	.....	34	421	4.5	0.0	15.7	6.6	11.7	31.8	21.6	....	8.1
American, Fairoaks		146	17	.39	11	4.4	11	.0	41	12	.....	6.3	83	20.7	.5	13.4	5.3	13.4	24.4	14.6	....	7.7
Cache Creek, Yolo	64	....	16	.19	30	23	33	2.1	193	28	1.3	31	250	6.2	.1	11.6	8.9	12.7	37.6	10.7	0.5	11.7
Feather, Oroville		41	16	.17	13	5.7	14	.0	64	11	.....	5.8	99	16.4	.2	13.3	5.8	14.3	32.8	11.3	....	5.9
Kern, Bakersfield		163	18	.15	18	4.2	22	.0	71	21	.....	9.1	127	14.1	.1	14.1	3.3	17.3	27.5	16.5	....	7.1
Merced, Merced Falls		52	14	.10	9.1	3.8	9.3	.0	35	11	.....	5.6	65	20.0	.2	13.0	5.4	13.3	24.3	15.8	....	8.0
Mokelumne, Clements		84	14	.18	12	3.8	13	.0	42	12	.....	7.3	75	16.8	.2	14.4	4.6	15.6	25.2	14.4	....	8.8
Russian, Ukiah	9	....	19	.19	23	12	16	.0	125	17	1.2	7.4	145	12.0	.1	14.6	7.6	10.1	39.4	10.2	.8	4.6
Sacramento, above Sacramento (1906)		69	19	.29	15	7.0	15	.0	76	13	.....	8.7	124	16.6	.2	13.0	6.1	13.0	32.2	11.3	....	7.6
Sacramento, above Sacramento (1908)	66	102	28	.43	13	6.7	13	.0	74	17	.64	5.4	113	23.2	.4	16.8	5.6	10.8	30.0	14.1	.5	4.6
San Joaquin:																						
Lathrop (1906)		60	16	.23	18	8.0	27	.0	66	26	.....	30	161	10.1	.1	11.4	5.1	17.1	20.9	16.4	....	18.9
Lathrop (1908)	34	52	19	.30	20	10	36	.0	74	39	1.0	47	205	9.1	.1	9.6	4.8	17.3	17.3	18.7	.5	22.6
San Gabriel:																						
Azusa	23	....	21	.16	45	12	18	3.3	176	32	1.1	4.3	208	9.4	.1	20.1	5.4	8.0	40.3	14.3	.5	1.9
Rivera	5	....	23	.11	55	12	22	2.2	211	33	1.9	8.4	246	8.8	.1	21.0	4.6	8.4	40.6	12.6	.7	3.2
San Lorenzo, Big Trees		84	23	.18	44	10	31	.0	147	43	.....	29	255	9.1	.1	17.4	3.9	12.5	28.5	17.0	....	11.5
Santa Ana:																						
Corona	65	....	31	.18	61	13	49	3.7	233	42	2.3	41	347	8.7	.6	17.1	3.6	13.8	33.0	11.7	.6	11.5
Mentone (1906)		55	16	.15	26	5.7	18	.0	102	14	.....	7.3	158	11.7	.1	19.0	4.2	13.1	36.4	10.2	....	5.3
Mentone (1908)	8	....	25	.16	25	6.3	18	.0	116	20	.75	3.8	145	16.0	.1	16.0	4.0	11.6	36.6	12.8	.5	2.4
Stanislaus, Knights Ferry		140	14	.20	11	5.0	11	.0	46	11	.....	5.6	83	17.3	.3	13.6	6.2	13.6	28.5	13.6	....	6.9
Tuolumne, La Grange		68	11	.19	10	4.3	12	.0	41	12	.....	6.6	74	14.4	.2	13.1	5.6	15.8	26.3	15.8	....	8.8
Yuba, Smartsville	191	....	14	.21	13	4.3	10	.0	48	13	.....	5.5	84	16.7	.2	15.5	5.1	11.9	28.6	15.5	....	6.5
Mean			19	.20	26	9.0	21	.75	105	25	.....	15	165	13.4	.2	14.7	5.3	13.1	30.7	14.3	....	8.3

Summary of results of analyses of surface waters of California from drainage areas receiving less than 15 inches annual rainfall.

Source of sample.	Average mineral content (parts per million).													Chemical composition of mineral matter (per cent of anhydrous residue).							
	Turbidity.	Suspended matter.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radical (NO_3).	Chlorine (Cl).	Total solids.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).
Arroyo Seco, Soledad	.....	33	26	0.20	51	14	29	0.0	170	72	....	13	284	9.0	0.1	17.6	4.9	10.0	29.0	24.9	....	4.5
Cottonwood Creek, Barrett dam	19	.....	44	.18	51	20	69	3.7	246	52	1.0	62	413	10.4	.0	12.0	4.7	16.3	29.5	12.3	.2	14.6
Estrella, San Miguel	161	.....	35	.19	79	53	224	9.6	273	385	.88	192	1,131	3.1	.0	7.1	4.8	20.1	12.9	34.6	.1	17.3
Malibu Creek, Calabasas	.....	61	36	.11	101	50	73	2.2	288	285	....	42	751	4.9	.0	13.8	6.8	10.0	19.7	39.0	....	5.8
Nacimiento, San Miguel	36	.....	25	.19	42	22	24	1.7	171	72	4.4	14	286	8.6	.1	14.5	7.6	8.3	29.8	24.8	1.5	4.8
Owens:																						
Charlies Butte	16	.....	43	.22	31	12	69	.0	211	54	1.7	33	339	12.4	.1	8.9	3.4	19.8	29.9	15.5	.5	9.5
Round Valley	7	.....	40	.20	15	4.3	40	.0	111	30	1.2	17	189	19.7	.1	7.4	2.1	19.7	27.2	14.8	.6	8.4
Salinas, Paso Robles	16	.....	31	.15	60	28	59	5.6	272	97	.74	39	448	6.8	.0	13.2	6.2	13.0	30.7	21.3	.2	8.6
San Antonio, Bradley	10	.....	37	.16	63	21	38	2.5	224	94	1.0	24	387	9.5	.0	16.1	5.4	9.7	28.9	24.0	.3	6.1
San Benito, Hollister	.....	1,444	24	.09	58	57	110	6.2	335	204	....	95	732	3.3	.0	8.1	8.0	15.3	23.8	2..3	....	13.2
San Luis Rey, Pala	.....	142	31	.12	42	13	44	.0	163	53	....	39	321	10.3	.0	13.9	4.3	14.6	26.5	17.5	....	12.9
Santa Maria, Santa Maria	.....	1,302	24	.14	302	133	200	.0	254	1,253	....	105	2,412	1.1	.0	14.1	6.2	9.4	5.8	58.5	....	4.9
Santa Ynez:																						
Santa Barbara (1906)	.....	64	24	.11	101	45	58	2.6	265	287	....	25	714	3.6	.0	15.0	6.7	8.6	19.9	42.6	....	3.6
Santa Barbara (1908)	32	.....	22	.15	109	49	66	2.4	258	373	.46	14	785	2.9	.0	14.3	6.4	8.6	16.9	49.0	.1	1.8
Santa Ysabel, San Pasqual	14	.....	44	.17	29	13	42	1.3	160	30	.84	38	260	16.0	.1	10.5	4.7	15.3	28.4	10.9	.3	13.8
Ventura, Ventura	3	.....	23	.14	106	30	47	3.9	226	251	.72	20	605	3.9	.0	17.9	5.1	7.9	19.4	42.4	.0	3.4
Mean	.....	.....	32	.15	78	35	75	3.1	227	225	....	48	627	7.0	.1	12.8	5.5	12.9	23.7	28.8	....	8.3

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MAP OF
CALIFORNIA
SHOWING DRAINAGE AREAS
AND LOCATIONS OF SAMPLING STATIONS

Scale [illegible]

REGULAR STATIONS

F. M. EATON 1906

I	American River	Fairoaks
II	Stanislaus River	Knights Ferry
III	Tuolumne River	Lagrange
IV	San Joaquin River	Lathrop
V	Merced River	Merced Falls
VI	Alameda Creek	Niles
VII	Sacramento River	Sacramento
VIII	Napa River	Napa
IX	San Lorenzo Creek	Fruitvale
X	San Benito River	Hollister
XI	Santa Ana River	Mentone
XII	San Gabriel River	Azusa
XIII	Santa Ynez River	Santa Barbara
XIV	Santa Maria River	Santa Maria
XV	Arroyo Seco	Soledad
XVI	Kern River	Bakersfield
XVII	Malibu Creek	Calabasas
XVIII	Mokelumne River	Lodi

WALTON VAN WINKLE 1908

1	Russian River	Ukiah
2	Cache Creek	[illegible]
3	Sacramento River	Sacramento
4	San Joaquin River	Lathrop
5	San Antonio River	Bradley
6	Salinas River	San Miguel
7	Estrella River	San Miguel
8	Salinas River	Paso Robles
9	Santa Ynez River	Santa Barbara
10	Cuyama River	Ventura
11	San Gabriel River	Azusa
12	[illegible]	Riverside
13	Santa Ana River	Corona
14	[illegible]	Murrieta
15	[illegible]	Elsinore
16	[illegible]	San Diego
17	[illegible]	Rincon
18	[illegible]	[illegible]

[illegible] TAKEN

1	Main River	[illegible]
2	[illegible]	[illegible]
3	[illegible]	Agua
4	[illegible]	Mecca
5	[illegible]	Mecca
6	[illegible]	[illegible]
7	[illegible]	[illegible]
8	[illegible]	Mecca
9	[illegible]	San Ana
10	[illegible]	San Mateo
11	[illegible]	Salton
12	[illegible]	Salton
13	[illegible]	Beaumont
14	[illegible]	Paso Robles
15	[illegible]	Victorville

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
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WATER-SUPPLY PAPER 238

THE PUBLIC UTILITY OF WATER POWERS AND THEIR GOVERNMENTAL REGULATION

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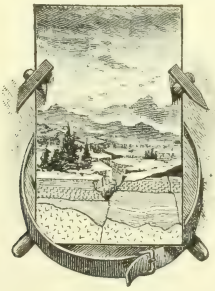

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THE PUBLIC UTILITY OF WATER POWERS AND THEIR GOVERNMENTAL REGULATION.

CHAPTER I.

INTRODUCTION.

By M. O. Leighton.

This paper is published to show how the French and the Swiss Republics and the Kingdom of Italy are treating a grave problem in their political economy—the problem of water power. The people of the United States are facing the same problem, although, except in a few notable localities, they have not begun to apply any method of serious treatment. The problem has grown well-nigh to maturity within ten years, and few have been aware. Had the country foreseen what has come to pass its treatment would have been easy. In its early years the issue might have been easily guided; now it will dominate a great controversy. The final result is not in question, but in the contest that must take place it will be wise to observe the nature and the drift of measures adopted by older countries and to learn all that may be helpful of their methods and acts. In this contest the following paper by M. René Tavernier, the distinguished chief engineer of the department of public works (ponts et chaussées) of the Republic of France, must be of value to the American people. As the delegate of his country to the Sixteenth National Irrigation Congress, convened at Albuquerque, N. Mex., in August, 1908, he presented a discussion of the subject of hydraulic power and irrigation which revealed so broad a conception of fundamental principles, and especially of the relation of the subject to national economy, that he was urged to increase the scope of his discussion to cover the subject-matter herein.

One of the striking features of the French discussion here and elsewhere is the apparent appreciation by all who have participated in public discussion of the fact that the problem has two sides. Corporate abuses—past, present, and prospective—are recognized, and

the need for remedial legislation is practically undisputed. On the other hand, it is admitted, even by the most zealous advocate of governmental intervention, that correction does not mean repression. Hydro-electric properties have not, as a class, returned to the investor a succession of swollen dividends. The industry has hardly passed its experimental stages. Its securities are by no means the least precarious of those on sale in the exchanges. This does not mean that such investments involve any special risk that is not presented, either in kind or equivalent, by other standard "industrials." Any project of the hydro-electric industry is profitable or unprofitable according as the expense of development and maintenance and the demand and supply are favorable or otherwise. The industry is subject to the same exigencies as are other industries, and, except in a few cases, notwithstanding the testimony of many popular magazine articles, it bears no resemblance to Aladdin's lamp as a revenue producer. No industry will respond more readily to ill-advised and oppressive legislation; in none must the burden fall more directly on the ultimate consumer. Any hydro-electric project requires special consideration during the early years of its development; a surprisingly large number either fail to pay dividends or become bankrupt during the first decade of their existence.

Notwithstanding the above statements, there is a real menace in the present situation, which holds many problems that are difficult of solution. Certain consolidations of water-power interests have taken place during the last few years, and these, with the appearance of the names of a few persons among the officers or in the directorate of a large number of companies operating water-power plants, making new installations, or manufacturing or marketing water power or electric machinery, point unmistakably to a concentration of ownership and administration in several groups which, in the usual course of events, might consolidate or at least effect a community of agreement. The menace in the prospect lies not so much in this probability as in the ability of such a combination to manipulate unrighteously the public interest. The menace is therefore speculative, but this fact does not obviate the necessity for legislation. The nation and the State are accustomed to legislate against speculative crimes and abuses, because experience shows that in the present state of society mankind is yet frail. What, then, should be the legislation necessary to meet the present conditions?

Consolidation is inevitable. Water power is a natural monopoly by reason of the natural laws of stream flow. Man can not change these laws, and his only course is wisely to adapt himself to them so that they may not operate to his disadvantage. The electric transmission of power developed on water wheels has changed the entire industrial aspect of the matter. When a water power was

used at the site and its industrial development was limited to its capacity there, no reason existed for consolidation; now the site of a water-power plant is not likely to be its field of operation; its power is distributed over a large area. In this large area there is a common demand for power, and the market constitutes an administrative unit. The demand of the region is a demand in the aggregate. The power on any stream fluctuates with the seasons. The important power demands are those which require a certain steady supply and a large reserve for extraordinary demands or "peak loads." As the demand increases with the development of industry the task of supplying it from one fluctuating stream grows more difficult. The energy developed on several sites or on several streams must then be transmitted to supply the market. With a still continued increase in demand, more sites and streams must be brought into use. In the final analysis, therefore, all sources of power available for a particular field of demand must be brought under a common administration, so that at any time the energy can be turned hither and yon to meet the requirements of each hour. It follows that legislation prohibiting power monopoly must not prevent power consolidation lest it injuriously affect industrial development. There is no virtue in preventing consolidation if economies in maintenance and operation are thereby prevented. No one will deny that water-power consolidation secures distinct and unusual economies, and if the consumer receives the benefit therefrom he is better off under consolidation. These are oft-stated and self-evident truths; therefore the proper solution of the problem must lie in the legislative regulation of water-power development and maintenance, to the end that the consumer shall pay a fair and reasonable price for power, consistent with the production of fair and reasonable earnings on the capital invested.

Up to the time of long-distance transmission of electricity a water power was an essentially local agent of production. The energy derived from the falling water was transmitted by belt and shaft to the near-by machinery which consumed it. Obviously, the field of operation was so localized that the plant was, to all intents and purposes, a private affair. Long-distance transmission of electricity made water power a public utility in every sense of the term. It entered a public market and became a common source of mechanical energy. A public utility is an enterprise in which there exists a public use. Although this term has never been strictly defined in a way that is applicable to all times and cases, the legal principle is well established. Mr. Justice Cooley, in defining a public use, as the term is applied in the law of eminent domain, said:

> The reason of the case and the settled practice of every government must be our guide in determining what is or is not to be regarded as a public use, and

it can only be considered such where the government is supplying its own needs or is furnishing facilities for its citizens in regard to those matters of public necessity, convenience, or welfare which, on account of their peculiar character and the difficulty of making provision for them otherwise, are proper, useful, and needful for the government to regulate.

This definition may suffice for the statement of principle. It implies that the public, in its sovereign capacity, retains the right of regulation and control in a greater or less degree over the exercise of any function of public consequence. When private property, or the use thereof, becomes a public necessity, or when the owner thereof devotes it to a use in which the public has an interest, he, in effect, grants to the public an interest and must therefore submit to control by the public for the common good *to the extent of the interest he has thus created.* Moreover, a public utility is absolutely defined by the controlling conditions of the times. That which is juris privati to-day may be a public utility to-morrow. The term must readily adapt itself to new demands and conditions imposed by the ever-increasing necessities of society.

When the principle above indicated is applied to water power under electric transmission, it will be seen that the conditions are satisfactorily met. Mechanical energy is one of the prime necessities of a productive people, and transmitted energy, distributed over an area, must, in the nature of things, dominate the situation. It becomes a public necessity, and when the power is devoted to such use the public acquires an interest therein, just as it acquires an interest in a railroad that, passing through any section of the country, becomes an agent of transportation, which is but another factor of trade and economic progress. It will not be contended that facilities for production are any less important to public interest than facilities for transportation. Viewed from every angle, the public economy in these two factors is identical in principle. One water power or a chain of powers may, under electric transmission, become the seat of productive energy over an area of 500 or 600 square miles, and this area will progressively increase with increase in the efficiency of electric transmission. Therefore present conditions of economic demand on such a source of power have by no means reached their limit, although the principle itself may be fully established.

The important point in connection with all this is that, whereas the appreciation of the people concerning public utility with respect to transportation facilities has been reflected in appropriate legislative acts, the public-utility features with reference to productive energy from water power are not realized, except in a few localities. It is true that for many years a water power from which energy is sold to mills has, under interpretations of the courts, been considered a public utility, but the principle was so limited in its application that,

previous to electric transmission, it did not impress the people at large with its real significance.

We are now facing the mature condition, and our legislative programme with reference to it is, in the majority of States, not even begun. So far as the attitude of the people is concerned, as represented in their legislative acts, water powers are on the same basis that they were years ago. The condition is equivalent to that which would prevail if our laws respecting transportation were still of the same scope that they were previous to the development of the steam railway. In addition to lack of law there are in some places constitutional limitations, and these are the greatest impediments to the inauguration of appropriate policies. Such is the conservatism of the people with reference to the change of the Constitution that a progressive demand must be apparent for a considerable period before a change is made that will apply to new conditions. Such conservatism is, of course, far preferable to an extreme tendency in the opposite direction, but, inasmuch as a constitution is fundamental law, it can hardly be considered praiseworthy to adhere to such law when the conditions on which it was originally based are so changed that a new field is presented. All this has been recognized in some European countries and in a few of the States of the Union, but the real significance of the present situation has not yet become a matter of common knowledge.

The disadvantages arising from our present unpreparedness to meet the new questions involved in power development and its regulation are not entirely internal. We might postpone action for several years without doing more actual damage to ourselves than to encourage monopolistic tendencies were it not for the fact that there is a matter of foreign competition, as is clearly implied in the following paper. This paper shows that the development of water power has become a national question in France as well as in Italy and in Switzerland. In those countries there has arisen a national policy of regulation and encouragement which will ultimately draw great industries within their borders. The United States now maintains an industrial leadership that can not be retained if other countries pursue policies that more strongly attract manufacturing enterprises. The menace to American industrial leadership is already on the horizon. The water-power sites of Europe are situated close to the great markets of the world. Is there anyone in the United States so confident of this country's industrial leadership as to assert that the wholesale development of these large and cheap powers will not seriously affect our status? Trade and production are entirely cosmopolitan. The cheapest sources of energy will be used, without reference to any particular flag, if they are located in a region convenient to market. This nation has now

no water-power policy worthy of the name. The President has recognized this defect, and in a special message to Congress on the conservation of natural resources, transmitted January 14, 1910, has advocated a comprehensive measure to meet the situation. Unless this or a similar proposal is adopted the United States must give way to those countries which have well-defined policies.

In many parts of the United States the price of coal is high and water power can be developed with comparative cheapness, so that a low rental price of power will yield a fair profit. The equitable way to maintain such powers is to charge only such rental as will pay a reasonable profit. But this policy is not always adopted. The tendency is to regulate the price of water power by the cost of steam power. If, for example, the rental of water power at $25 per horsepower year will furnish a satisfactory margin of profit, and the cost of steam-power production is $100, then the price of water power is fixed not at $25, but at a point nearer $100. In this way the water power will be a trifle cheaper to the consumer than steam power, and therefore the former will control the market. This is obviously an extreme case. The margin between the cost of the two kinds of power is not usually so wide. The statement does, however, illustrate a common practice. Such an arrangement obviously does not afford to the community the real saving that should result from water-power development. An industrial power consumer will inevitably compare the results of such a system with the prices and conditions that prevail in foreign countries. This is a mere matter of wise business management. If, in looking over the ground, the consumer finds that under the laws of France or Switzerland he can obtain his power at the $25 rate or its equivalent, he is not going to locate in a part of the United States where it is worth only the $25 rate but where, by reason of the differential on steam power, it is raised nearly to the limit at which steam power can be produced. Of course other factors than power costs influence the location of any manufacturing plant, but this does not justify the imposition of a handicap on the United States in the shape of unrestrained or unregulated power charges.

The above statements are intended to suggest in a superficial way that in this matter of power development the adjustment of questions in dispute does not merely involve an extended squabble among ourselves. The question has a higher significance, namely, that of the productive leadership of the United States. In the face of the activity of European countries, concerning which no secret is made, there can hardly be any excuse for the postponement of rational and legal measures by this country. The discussion submitted by M. Tavernier in the following pages should not be regarded simply as an interesting dissertation on water powers and their rela-

tion to political economy, but rather as a lesson from the experience of another enlightened country and a warning that measures at least as foresighted and progressive must be adopted by the States and the nation.

M. Tavernier has selected certain extracts from reports previously made by himself; also certain reports of commissions of the Chamber of Deputies, in which are presented and discussed sundry legislative proposals. All of this is supplemented by a presentation of various laws enacted by certain States of the Union and a general introductory discussion of the popular and legislative status of water power in the United States, which has been prepared by the coauthor.

CHAPTER II.

HYDRAULIC POWER AND IRRIGATION.

By René Tavernier.

GENERAL STATEMENT.

It was little more than thirty years ago, shortly before the well-known experiments of Desprez concerning the electric transmission of power, that French engineers began to perceive the use that could be made of the power of flowing water. A hydraulic power plant, operated by a waterfall 500 meters (1,640 feet) in height, built by M. Berges for the use of his paper mill in the Isère Valley near Grenoble, drew attention to the large number of similar industrial opportunities throughout the French Alps.

The example of M. Berges found a number of imitators. Between 1880 and 1890 several manufacturers in the valleys of Arc and Romanche rivers made use of the streams and falls of that region for electro-metallurgical and electro-chemical purposes. The first great hydraulic plant designed to produce power for public distribution was erected in the period between 1888 and 1898 on Rhone River above Lyons, at the town of Jouage. By the year 1900 such plants had become so numerous as to call for a governmental investigation of their possible effects on the future work of certain branches of the public administration, particularly that of the division of irrigation.

On August 12, 1899, the writer prepared a report containing detailed information concerning the exploitation of this new variety of wealth, which in France has been somewhat metaphorically called "white coal"—"la houille blanche"—and the means by which public service enterprises using hydro-electric power, as well as those concerns whose operation is affected by the diverting or damming of streams, may be enabled to participate in this exploitation and derive profit from it.[a]

Among the enterprises that simply consume hydro-electric motive power should first be mentioned the great railway systems, which in France, as every one knows, are leased by the State to private corpo-

[a] Les forces hydrauliques des Alpes en France, en Italie, en Suisse; statistique—mode d'utilization—législation: Rapport de mission de M. René Tavernier, ingénieur en chef des ponts et chaussées (Annales des Ponts et Chaussées, 1900). (See pp. 37–73.)

rations and which revert to the State at the expiration of the leases; among those whose development and prosperity are even more directly affected by the production and utilization of hydraulic power are navigation (confined to navigable streams) and irrigation (extending to all streams).

This paper, written entirely with regard to the interests and needs of agriculture, is intended to emphasize the close interdependence of irrigation plants—particularly their future expansion and utilization—and the industrial employment of hydraulic power. Its statements apply especially to France and are probably not sufficiently general in character to be applicable without modification to all other countries. France is densely populated, and a relatively large number of her inhabitants own the farms that they cultivate or the shops or businesses that they manage. Neither manufacturing nor agriculture is there conducted on so large a scale as in America, nor does either play a predominant part in any one section of the country, as in the United States, where some of the separate States are mainly agricultural and others mainly industrial. In almost every portion of France agriculture and manufactures are distributed almost evenly and play parts of about equal prominence.[a]

This problem of the more satisfactory utilization of streams, which is bound to arise sooner or later nearly everywhere, presents peculiar difficulties in France because of the entanglement of economic interests and the conflict of legal privileges which are involved. Few streams are serviceable for only one purpose. Since time immemorial the right to use even little brooks and creeks has been a matter of dispute between individuals; and now that the larger streams have suddenly acquired very considerable economic importance the conflict of interests is more vital. In seeking the better utilization of streams it is often necessary to defend the future needs of agriculture, which provides a livelihood for a large population without enriching those who are engaged in it, against the encroachments of manufacturing plants whose exclusive purpose is the earning of large profits.

We shall consider, first, the relations between hydraulic power production and soil irrigation; and then discuss the investigations made by the French ministry of agriculture, as well as the measures which it has already taken or proposes to take in this connection.

INFLUENCE OF INDUSTRIAL UTILIZATION OF HYDRAULIC POWER ON DEVELOPMENT OF IRRIGATION.

The proper discussion of the question indicated by the above heading requires the consideration of the following three topics:

[a] Similar conditions are approaching or are already fixed in many parts of the United States. It is the natural consequence of age, opportunity, and development.—M. O. L.

(1) The methods of irrigation employed in France; (2) the economic features that are peculiar to hydraulic power enterprises; and (3) the relations between these two sorts of enterprises, including the mutual help that they can render under certain circumstances and the harm which, under other circumstances, they are apt to inflict upon each other.

FRENCH IRRIGATION METHODS.

A lengthy exposition of this subject may be dispensed with by referring the investigator to the following works:

Barral: Les irrigations dans les Bouches-du-Rhône.
Barral: Les irrigations dans Vaucluse.
Barral: Les irrigations dans la Haute-Vienne.
Annales de la directions de l'hydraulique et des améliorations agricoles (parts 26 to 34).
Reports of the International Congress of Engineers at St. Louis, Mo., U. S. A., irrigation section. (In English.)
M. Lévy-Salvador: Irrigation and hydraulic motors used in irrigation in France.
Prevost, M., Ingénieur au ministère des colonies: Rapport sur les irrigations aux colonies.
Alimentation artificielle de la rivière de Neste.
Note sur le service de l'hydraulique et des améliorations agricoles.
Map, on a scale of 1 to 5,000, of the basin of Durance River and its tributaries.

Particular attention is directed to the short article on irrigation by M. Lévy-Salvador, which has been translated into English[a] and which gives the reader a general idea of the various methods used in different parts of France. As agronomic questions will not here be discussed, but attention will be devoted exclusively to the mechanical or engineering aspects of irrigation, the means by which water is carried to the soil to be irrigated, it may be stated, in agreement with M. Lévy-Salvador, that two methods have always been in vogue. With the first method surface water or underground water is pumped at the point where it is to be utilized; with the second it is led through gravity canals and ditches from some point at a distance, where the level is sufficiently high, to the place where it is to be used. Each of these methods has heretofore had its own peculiar advantages under given circumstances. Pumping has been used especially for private small-scale irrigation, where small volumes of water were used separately and pumped to relatively low altitudes; but the method of diverting the requisite water has always been regarded as a more economical way to provide large quantities of water for the irrigation of groups of farms collectively.

But the purely mechanical superiority of the diversion method was conjoined with a commercial inferiority which explains the financial

[a] Trans. Am. Soc. Civil Eng., vol. 54, pt. C, 1905, pp. 111–128.

failure of the newest large irrigation plants. This commercial inferiority was due to various causes which, in the last analysis, all had a common origin in the fact that the small farmers interested in the collective enterprises were very numerous and possessed extremely scanty financial means. In France, as in some other countries, the demand was not for an irrigation system adapted to the needs and resources of a small number of large landed proprietors who could easily be persuaded to combine themselves in a venture of financial magnitude or who cultivate a virgin soil which is apt to increase sufficiently in value to yield large profits to the promoters. The numerous landowners whose farms require irrigation must be led to unite and they must pledge themselves for a long period—forty years or more—in order to insure the continued operation of the irrigation plant. In spite of very large subsidies (often amounting to half the cost) granted by the French ministry of agriculture, disasters of two kinds have arisen.

1. Landowners who have subscribed—ill-advisedly—for the watering of a relatively large acreage have been unable to earn any profits, because of the poor quality of the soil, the great distance from the market, or the insufficiency of their capital. For it should be noted that the change from arid soil and extensive methods of farming to irrigated soil and intensive methods involves not only the expense of irrigation itself, but also the oftentimes heavy burden of altering methods, new implements, and a different management. The farmer who can not meet these demands and adheres to the old methods of cultivation finds that the water which he has so dearly bought does not result in a sufficient increase in the value of his crops.[a]

2. The owners of the plant find unfulfilled, as a result of the same circumstances, their own reasonable hopes for expanding demand for irrigation and hence increasing profits.

The disappointment of some of the early subscribers to the enterprise also dissuades possible new ones. Even the method of selling the water, namely, by requiring the purchaser to pledge himself for a long period and for a certain number of acres, without the possibility of subsequent modification, is altogether unbusiness-like. Intensive farming, like most other occupations, is subject to shifting and fluctuation and does not permit rigid calculations made in advance for long periods of time. Some farmers would be willing to try an experiment, but would not dare to bind themselves for a term of years.[b]

[a] The usual prices, varying from 40 to 60 francs per hectare per annum (about $3 to $4 per acre per annum), entitle the purchaser to a quantity of water equivalent to a flow of 1 liter (0.035 cubic foot) per second, furnishing a depth of 6 centimeters (2.4 inches) every week for six months of the year.

[b] The similarity of difficulties in connection with cooperative enterprises in the arid West of the United States is worthy of remark.—M. O. L.

It is easy to understand, moreover, that in time these difficulties will probably disappear. Landowners learn to make good use of the water, and those who do not at first possess sufficient means or knowledge acquire them gradually, or their places are taken by others who are more resourceful. Furthermore, numerous farmers' unions and cooperative associations interested in the social reform movements now so active in France have provided groups of associated farmers with all the resources formerly enjoyed only by large landowners.

Finally, the department of agriculture, by means of a newly created service—"the agricultural improvements service," complementary to the hydraulic service—is itself endeavoring to aid irrigators to the best possible utilization of water.[a]

Many of the older irrigation plants have reduced their charges and better adapted themselves to local conditions, thus, in the long run, bringing about fortunate transformations and spreading prosperity in the regions where they are located. It would be wrong, therefore, to conclude that because some of the large systems of irrigation canals recently built in the valleys of the Rhone and the Durance were financial failures irrigation does not constitute in the south of France, or in countries presenting similar climatic conditions, a most efficient means of increasing agricultural productivity.

But it is equally comprehensible—and this is the main point of the foregoing remarks—that the ministry of agriculture hesitates to subsidize new irrigation enterprises while those most recently completed have not yet produced the results which were anticipated; and that the Government prefers to seek some solution which shall offer, among other advantages, that of not involving large expenditures made too long before the time when they can become profitable.

In the following paragraphs we shall consider to what extent the results of the utilization for productive purposes of the so-called "white coal" will retard or facilitate the discovery of a solution.

ECONOMIC NATURE OF BUSINESS ENTERPRISES EMPLOYING HYDRAULIC POWER.

Up to the end of the last century small hydraulic plants and water mills, which were very numerous in France, employed only a small fraction of the total water power of the country. In 1890, according to the statistics of the department of agricultural hydraulics, these concerns numbered 69,620 for the whole of France, with a gross productivity of 1,028,807 horsepower, equivalent, because of the small yield of very imperfect appliances, to an effective horsepower of only

[a] See bulletin entitled "Review of the work of the bureau of hydraulics and agricultural improvements," a translation of which appears herein (pp. 93–107).

one-third that amount. The average productivity of each mill or plant was 14 horsepower gross and 5 horsepower net. These small plants, when erected upon streams well supplied with water, generally used only a fractional part of the available power and water and left the remainder available for other purposes, such as irrigation. But this is not the case with large modern power installations, where a single plant gathers up several thousand horsepower. In the region of the French Alps alone—which, to be sure, is best provided with hydraulic power—there are 90 plants producing a total maximum of 325,000 horsepower, measured at the turbine axle, or an average of 3,600 horsepower for each concern.

The report of the writer, referred to on page 12, contains numerous facts concerning the cost of first establishment and of maintenance and operation and methods of utilization of large modern water-power plants. Since that report was written (in August, 1899), the "white coal" industry has made rapid progress. But the broad features of its evolution are marked in the schedule prepared more than ten years ago. Some modifications should, however, be made therein. As the laws authorizing expropriation have not yet been put to a vote, the riparian owners and intermediaries of all classes, having come to a greater realization of the value of water powers, have raised their prices to a considerable degree. The sum of 100 francs ($20) per horsepower, taken in 1899 as representing the total expense of first installation of water-power works, is to-day in some places entirely absorbed in the mere acquisition of riparian rights.

Another feature in the progress made during ten years in the method of utilizing large water-power plants is indicated by the large power-distribution enterprises. Such enterprises, employing the technical inventions that continue to extend the practical limits of long-distance transmission, have sprung up in various parts of France in which water powers are located—principally in the southeast, in the region of the Alps, and in the southwest, in the region of the Pyrenees—just as, during the past ten years, the large railway systems have grown by combinations and successive extensions. The analogy between these two economic phenomena is striking.

To make the large railroad companies respect the principle of equality in treatment of the people, to safeguard industrial and commercial liberty, has been the universal endeavor, and the value of the results has varied with the efficacy of the precautions adopted. The experience acquired in the past in the exploitation of railroads must be applied to the better organization of the public services for power distribution.

The new tendency is to build, at the very start, a series of canals that will divert the entire low-water flow of the streams. Many of the large plants are fitted up not only for operating with the mini-

mum flow that can be counted on at all times of the year, but also for using the average flow such as may be reckoned on more or less irregularly during only eight, six, or even fewer months of the year.

It is evident that such an elaborate undertaking—sometimes called a "complete" plant—is likely to jeopardize the development of irrigation unless some precaution is exercised. Of course existing provisions for irrigation are not interfered with. There is even a disposition to allow a certain "margin," which takes into account the probable demands of the future, based on the needs of the past. But when new irrigation enterprises are projected after such "complete" power plants have been built they are apt to come into conflict with vested privileges upon which it is impossible to encroach without indemnification.

It is true that hydraulic plants do not actually use up the water itself, which is always available for application to the soil after it has passed through the wheels. They do not interfere with the use of the water for irrigation below the point of exit. They prevent its use above that point. They consume the fall necessary to carry the water to the fields lying at altitudes between the upper and lower levels of the power plant. Hence the erection of one of these "complete" or integral power plants amounts simply to appropriating the impetus of the stream, which also constitutes, so to speak, the "energy" necessary for watering the soils that might benefit by irrigation. It may be more profitable for all parties—as we shall attempt to show later—to resort to the system of storing up this "energy" rather than to that of storing up water taken at the upper level of the fall. But before considering this question we must clearly grasp the dissimilar economic characteristics of the various types of hydraulic plants—characteristics that depend upon such circumstances as the altitude of the fall, the volume of water and its fluctuations, whether the stream is tapped by a channel at a higher level or the water dammed at the point of use, and whether it is possible to accumulate the flow and to regulate the plant without loss of water but in accordance with the demands of its customers.

In France the productivity in horsepower of a hydraulic plant is calculated by means of the following very simple formula: $P=H\times Q\times 10$, in which H is the height of the fall in meters and Q the discharge in cubic meters per second. This gives us the gross productivity in horsepower, each of 100 kilogram-meters[a] per second, which corresponds at the turbine axle—assuming a net yield of 75 per cent—to a horsepower of 75 kilogram-meters per second.

But the industrial value of a power plant is not measured solely by its power thus calculated. In the first place, the formula is inapplicable to a plant using, in addition to a permanent minimum flow

[a] This is the French horsepower, equivalent to 1.32 British horsepower.—M. O. L.

of water, a certain average intermittent volume. An irregular power is manifestly not equivalent to a uniform power, when the irregularity is independent of the requirements of consumption and is governed solely by fluctuations in the condition of the stream. On the other hand, if a plant is equipped with facilities for storing up the natural flow of the stream for a time at a higher level in order to make use of it at the periods of maximum consumption, irregularity in the production of energy becomes subject to control and constitutes a source of large additional gain. It should be remarked, moreover, that these profit-creating reservoirs are much more effective and economical with high than with low head plants. Compare, in this respect, two hydraulic plants of 10,000 horsepower each, one receiving a flow of 71 cubic feet (2 cubic meters) per second, with a fall of 1,640 feet (500 meters), and the other a flow of 7,100 cubic feet (200 cubic meters) per second, with a fall of 16.4 feet (5 meters). A reservoir of 2,542,600 cubic feet or about 58 acre-feet (72,000 cubic meters) would suffice, in the first case, to store up the total discharge of ten hours, enabling that plant to vary its production sufficiently to provide for the widest fluctuations in the daily demand. In the second case a reservoir 100 times as large—that is, with a capacity of 254,260,000 cubic feet or about 5,800 acre-feet (7,200,000 cubic meters)—would be needed to obtain the same results. High falls therefore admit much more readily than low falls of being so equipped as to produce power at the precise time of the day when it is wanted. But they may play an even more important part. Imagine a poorly fed basin in a mountainous region receiving during the year by irregular discharges a total volume of water equaling a regular and uninterrupted flow of 3.5 cubic feet (100 liters) per second. With a reservoir having a capacity of 83,794,000 cubic feet or about 1,902 acre-feet (2,372,840 cubic meters) the water could be stored during nine months in order to let it flow during the remaining three months. If the height of the fall is 1,640 feet (500 meters), the creation of this reservoir would mean substituting for an average force of 500 horsepower, that is altogether useless because of irregularity of the flow, an additional force of 2,000 horsepower that is extremely valuable because it may be used at the very season when it is needed. Here we have a "seasonal" regularity, which not only enables us to meet varying seasonal demands, like those of agriculture or of the distribution of electric light, but which also makes it possible, whenever several plants are concurrently engaged in furnishing power for one distributing concern, to come to the aid of those plants whose productivity is intermittent and not subject to such regulation.

In short, it will readily be seen that the industrial value of a large hydraulic plant does not depend solely on the maximum amount of

power that may be produced, but differs considerably as the power is produced permanently and regularly or intermittently, and also according to the extent and nature of the irregularity. Unavoidable and unforeseen irregularities in power production, due to the effect of changes of wind and weather on the condition of rivers, cause an enormous diminution in the industrial value of a hydraulic plant. But when the production of power is subject to such regulation and control as is made possible by reserve supplies of water, fluctuations in production may be made to coincide with fluctuations in demand.

The various systems of producing hydro-electric power having been characterized, a word should now be said as to the nature of the market. Thus considered, hydraulic plants may be divided into two very distinct groups—(1) isolated plants built in connection with various sorts of industrial enterprises, such as electro-metallurgical or electro-chemical manufactures, and adapted to the permanent or variable needs of productivity of the enterprises concerned; such plants, sufficient unto themselves, are essentially private and nothing need be said of them except that they are chiefly found in mountainous regions; (2) plants that supply power for one or more enterprises and are designed to furnish the public with motive energy. These plants are of interest here because economy requires that the various uses of the motive power thus distributed should include a sufficient provision for pumping water for irrigation.

The hydro-electric power supplied by such plants will be in demand by many kinds of consumers with exceedingly varied needs. For illumination the motive power is needed at certain definite times and during a limited period of two or three hours on an average day.[a]

The power needed by motors used in manufacturing concerns is required for periods as long as the workday of the laborers. The demands for traction depend on the time-tables of the railway companies or of the street-car companies. All these enterprises, which are rather irregular and capricious in the need of power, nevertheless require that power at certain very specific times. It is natural that the price which must be paid should be proportionate to the specific demands, and this, as a matter of fact, is the practice in France, as is shown by the following table of rates customary in France:

Cost per kilowatt-hour.

For illumination	50 to 80 centimes (10–16 cents).
For small quantities of 20 to 50 horsepower	9 to 20 centimes (2–4 cents).
For larger amount of power transmitted some distance	4 to 6 centimes (8–12 mills).
For power furnished at the business place itself	1 to 3 centimes (2–6 mills).

[a] This evidently refers to the "peak load" for lighting.—M. O. L.

The organization of large corporations for the public sale and distribution of power furnished by hydraulic plants is sufficiently advanced in certain parts of France, such as the southeastern region, to indicate the essential tendency of such concerns, which is to bring together into a systematic unit, by means of electrical connection, all the power-producing plants and all the consumers of power in a given section of the country.

A consolidation of this sort is being effected between Nice and Montpellier by the Société de l'énergie électrique du littoral Méditerranéen. A similar monopolistic tendency is drawing together the central steam-power plants, which have been established in the cities by the street-car companies, or the older electric-light plants, which are still maintained to serve as emergency stations to help out the hydraulic plants at times of accident or unusual demands for power. It frequently happens that steam plants are operated a few hours daily to furnish a sufficient margin of power to insure against possible shortages through unusual demands (peak loads). But the part played by such emergency steam plants will diminish to the extent that the flow of streams is made more regular through the use of reservoirs and the erection of "regulating" hydraulic plants.

A concern which thus monopolizes, throughout a vast region, all the different varieties of hydraulic energy, correcting the weak features of each variety by means of systematic organization and control, engrossing the entire market for power, and regulating the total production by virtue of the simple fact that the demand is ever becoming greater and more varied, possesses such great economic and commercial advantages that no independent concern is in a position to furnish power for any special purpose at a lower price.

The various uses which we have enumerated, with the exception of electro-metallurgical manufactures (which are able to make good and complete use of a great hydraulic power plant), can not be economically provided with power by the separate concerns themselves. A hydraulic power plant built for the special purpose of illumination or traction is necessarily imperfectly and only partially utilized, because the unused residues of power are apt to be considerable.

Undoubtedly the rational "trustification" of the distribution of hydro-electric power has thus far been confined to southeastern France. But, inasmuch as irrigation is most advanced and best developed in that region, and inasmuch as the same evolution is likely to take place elsewhere, it is interesting to inquire what care may be taken under such circumstances to safeguard and foster the reasonable needs of agriculture, and under what conditions hydro-electric power may be equitably utilized to pump water for irrigation as well as for the other uses required by the public.

USE OF HYDRAULIC PLANTS IN THE DEVELOPMENT OF IRRIGATION.

Pending the discovery of new methods of bringing water for purposes of irrigation to the places where it is needed, it would be absurd to condemn the old methods and to insist unduly upon the general application of the methods about to be described. Many isolated and independent irrigation enterprises will undoubtedly continue to be justified; but, while the industrial utilization of streams is made on a large scale, as on Durance River and its tributaries, it is questionable whether the separateness of irrigation enterprises does not constitute a source of weakness and a hindrance, and whether a possible antagonism of interests in the future might not be avoided by bringing together several systems for utilizing the streams.

From purely mechanical considerations, it may at first seem surprising that there should be an advantage in employing expensive mechanical devices, such as turbines and dynamos, whose use results in considerable loss of energy, rather than in continuing the exclusive use of gravitation. But a little reflection suffices to justify this conclusion as to the relative merits of the two systems.

We must first of all eliminate from the discussion the objection of "lost energy." Without carrying the comparison very far, it is easy to estimate a priori the loss of energy involved in the usual system of irrigating by diverting streams—losses which are due to the excessive slope of small trenches, and, above all, to the fact that the large accumulating channels carry all the water to the highest level of the area to be irrigated, without the possibility, as a rule, of diverting any considerable portion of the propulsive power of the water that is employed at lower levels.

By the use of separate pumps, each of which raises to the necessary level the water needed for irrigating at that particular level, the greater part of this loss of energy may be avoided. Moreover, very considerable losses of water caused by the long main channels may be avoided by a series of separate pumping stations.[a] Finally, whether it is utilized or not, the maximum volume of water flowing into a large irrigation trench should always be available. Under the system of pumping stations the quantity of water brought to a given level corresponds exactly to the requirements of the consumers. Without doubt, in the gravity system of conducting the water the total waste of water or of power does not greatly exceed the mechanical loss due to electric transformation and to the transmission of power made necessary by the pumping process.

[a] The Bourne channel furnishes a typical example of the magnitude of these losses of water, which, in this instance, exceeds half the entire volume that is diverted into the channel.

From considerations of original expenditure and trouble of maintenance, the complexity of mechanical and electric installations, compared with the simplicity of a channel which accomplishes this work by means of its slope, would constitute a marked disadvantage in the new process if we were simply comparing two isolated and autonomous enterprises; but our hypothesis assumes that in pumping we have to do with a large enterprise for producing and distributing hydro-electric energy and furnishing water for a large number of irrigation areas as well as other public and private uses.

Isolated irrigation plants in this way escape the difficulties connected with the production and transmission of power; they receive for a fixed price the power required to carry the water to the desired level; and the financial superiority of the pumping station is thus due to the fact that the annual expense of the station, added to the cost of maintenance and keeping the plant in repair, is lower than the annual cost of constructing and maintaining the main channel in the system of diverting streams.

The following figures will give some idea of the height to which water may be pumped without greater costs than those usually incurred in agriculture:

Watering 2.471 acres (1 hectare) of land with a volume of water equaling a continuous discharge of 0.035 cubic foot (1 liter) per second for six months will mean, if the water is raised 39.37 inches (1 meter) a power in pumped water of $\frac{1}{10}$ horsepower throughout the year, or of 42.98 kilowatt-hours. If the total yield of the pumping station is 60 per cent, including dynamo, pump, and pipes, the annual consumption of power will be 71.6 kilowatt-hours, and the cost, at a rate of $\frac{1}{5}$ cent (1 centime) per kilowatt-hour will be 14 cents (71.6 centimes). If the price per kilowatt-hour is X centimes and the elevation N meters, the annual expenses for pumping the water necessary to irrigate a hectare, according to the formula 0.716 XN, will be as follows:

Cost, in francs, of pumping water necessary for irrigating 1 hectare (1 liter per second).

Height (meters).	Cost when price of kilowatt hour, in francs, is—				
	0.01	0.02	0.03	0.04	0.05
10	7.16	14.32	21.48	28.64	35.80
20	14.32	28.64	42.96	57.28	71.70
30	21.48	42.96	64.44	85.92	107.40
40	28.64	57.28	85.92	114.56	143.20
50	35.80	71.60	107.40	143.20	179.00

These figures may be compared with the cost per liter per second diverted by some of the great irrigation canals in southeastern France:

Cost per liter per second (equivalent to watering 1 hectare) of water from canals in southeastern France.

Canal.	Capital value of first plant.	Annual interest at 5 per cent.
	Francs.	*Francs.*
Marseille	5,000	250
Verdon	3,500	175
Manosque	2,000	100
The Bourne	1,600	80
Pierrelatte	1,150	57.59

Even when reduced to this definite basis, the comparison is rather difficult to make and is subject to some variation. For the pumping stations one may employ either a continuous supply of power furnished at the average price charged by the distributing plant or the residues of power provided intermittently at lower prices.

Irrigation plants may, in fact, prove less exacting than lighting or traction plants as regards the period and the duration of power consumption. They may either utilize regularly and fully the power produced continuously by the hydraulic plant, or utilize only for certain hours daily the residues which are available in every plant that furnishes power to be distributed to a considerable number of different concerns.

Intermittent pumping, compared with continuous pumping, involves certain supplementary costs and expenses of maintenance. The capacity of the pumps themselves must be augmented as well as that of the main trenches. Moreover, unless reservoirs are built along the distributing trenches the soil can be watered only at certain times, determined by the times when the residues of power are available. These costs and difficulties must be compared with the saving effected by the reduction in the price of power. It would surely be equitable to insist on a considerable reduction in price for residues of power for which no other use than pumping can be found. Two considerations, however, may stand in the way of such a reduction. It may happen that the amount of these residues is diminished by the steam-power plants that provide power in cases of emergency. We have pointed out that this is true in the large power-distributing plant that supplies the southeastern part of France. It may also be urged that the furnishing of power for irrigation during a period limited to six months or less per annum involves leaving, during the remaining six months, additional residues of power very difficult of disposal.

The devices to be adopted to obviate these difficulties and to enable pumping stations to obtain their power at the lowest possible prices depend on conditions peculiar to each particular plant and region. Thus, for example, where streams are fed by melting snow and glaciers, as in the valley of the Durance, it is possible to obtain a greater supply of power at the very season when the demands of irrigation require it. The warmth that fosters vegetation also causes an abundance of water in glacier-fed streams. This fortunate coincidence is perfectly satisfactory at the beginning of the irrigation period but does not always last to the end. There is often a shortage in September in the valley of the lower Durance. The construction of large reservoirs, the possibility of which is now being investigated, will prevent shortages and at the same time insure regularity in the production of hydro-electric power.

In the writer's opinion, the chief advantage of a system of pumping by hydro-electric power is that the energy may be furnished by a great distributing plant which supplies a whole region with power. This permits dividing the work of irrigation among a number of successive stations, erecting at the outset only those that are likely to be remunerative, and keeping pace with the natural growth of the demand for irrigation instead of tying up capital for a long time before it becomes productive. The adoption of such a plan will remove the principal cause of the financial failure of the large irrigation systems recently built.

Again, under this system, the benefits of watering the soil are no longer confined to areas that can be reached by the large gravity channels which are so difficult to build and require so much time. Considering the probable rapid spread and development of large distributing plants for hydro-electric power, it may be said that if the price charged per kilowatt-hour is fixed low enough, our entire territory may be irrigated by pumping on a larger or smaller scale. However cheap a kilowatt-hour may be, the areas devoted to extensive farming will be unable to stand a charge of more than $3.25 to $4 per acre (40 to 50 francs per hectare), and hence can not buy the water if it must be carried to too high an altitude, but this will not be true of truck farming in the neighborhood of cities. In many places it will be profitable to supply both the city and its environs by having the same plant provide drinking water, and thus obtaining the large receipts which this involves. Underground waters, as well as surface waters, accumulated in reservoirs will then be supplied to the soils which make the best use of them.

Each stream can thus be employed to the best purpose, either as a water supply or in producing motive power. Thus water power of the Durance, which at the periods of low water does not supply suf-

ficient water for irrigation of all lands in its lower basin, could be used to lessen the disastrous effects of such shortages by developing power in the highlands to pump from the Rhone to irrigate a portion of the area now watered by one of the canals supplied by the Durance. Numerous contrivances to effect this result will then become possible. But enough has been said to give some idea of the advantages to be obtained. The administrative measures and the legislative reforms designed to facilitate these changes, which are under consideration by the minister of agriculture, will now be discussed.

MEASURES ADOPTED BY THE MINISTRY OF AGRICULTURE TO HARMONIZE THE DEVELOPMENT OF IRRIGATION WITH INDUSTRIAL UTILIZATION OF STREAMS.

Two kinds of general measures are adopted by the French ministry of agriculture to induce industrial plants that use water power to cooperate in the growth and development of irrigation; the first aim to make a complete and detailed study of streams; the second have to do with the licensing of hydraulic-power plants. A few data will be presented on each of these points and, by way of example, the special investigations now under way will be indicated.

BUREAU FOR INVESTIGATION OF HYDRAULIC POWER.

Investigation of stream flow.—It is evident that the rational development of hydraulic power, involving the employment, at the lowest possible price, of a portion of the power for pumping water for irrigation must be based above all on a thorough knowledge of the precise nature of streams and of all other surface accumulations of water that admit of direct use. Investigations of this sort were authorized by the minister of agriculture in 1903 under the joint direction, so far as the Alpine region was concerned, of Chief Engineer R. de la Brosse and the present writer. The expenditures in the region of the Alps alone amounted to about $20,000 (100,000 francs). It will be of advantage to summarize from the report of that investigation,[a] published in 1905, the main features of the plan then pursued, which was entirely analogous to that being followed upon a larger scale by the engineers of the water-resources branch of the United States Geological Survey.

The plan has a twofold object—first, the purely physical investigation, geographic, meteorologic, and hydrographic, of streams and their beds; second, the economic investigation of the questions raised by the utilization of the energy produced by water or by the use of water.

[a] Ministère de l'agriculture—Annales—Direction de l'hydraulique et des améliorations agricoles, fasc. 32; tome 1, Organization et compte-rendu des travaux; tome 2, Résultats des études et travaux.

No one will contend that it is possible in the hydrographic study of streams and their channels to pay attention to the lines of jurisdiction that divide the different Departments of the Government. The economic and legal discussions of the matters fundamental to the "white coal" industry have brought out certain facts clearly. The best utilization of a stream will almost always be a varied one, recognizing the complex interests of agriculture, manufactures, and public-service utilities of all kinds. It is therefore imperative that the entire subject be studied regardless of artificial lines of subdivision—not in order to place obstacles in the way of manufacturers, but to provide them with precise data, lacking which they might undertake disastrous schemes, and also to furnish a basis of action for the Government. The "white coal" congress, held at Grenoble in September, 1902, adopted a resolution to this effect, which contained valid arguments. If we compare the spread of the hydroelectric industry in the French, Swiss, and Italian Alps, we will discover that the exact determination of the hydraulic power of our streams is much less advanced than in the neighboring countries, and that the meagerness and inaccuracy of the data upon which the first enterprises were launched in France have been the cause of some unsatisfactory results. The following statements are applicable only to the Alpine region comprised between the Rhone and the Franco-Swiss and Italian frontiers.

Number of measurement stations.—The number of stations which should be maintained in the Alps to determine with some degree of precision the hydraulic power of the streams can not be estimated at less than 200, which would mean an average of 20 for each Department, or 0.30 per square myriameter (1 station for each 129 square miles). The stations already built are still far from being equipped with all the apparatus necessary for doing good work, but efforts are being made to equip them as rapidly as the available funds permit.

Utility of a preliminary estimate.—It will be several years before we are in a position to give accurate information concerning the régime of Alpine streams, but we have undertaken from the start to coordinate such data as we possess, making use even of those that are incomplete and hypothetical, so that it would be possible to prepare a sort of provisory inventory, which might be rectified from time to time and brought up to date. This first task will make plain the deficiencies in data. It will be a sort of sketch, with blank spaces that will be gradually filled out and perfected by substituting every year, for the approximate data previously used, the more exact figures resulting from a longer experience.

Practical nature of the results to be obtained.—Our principal purpose has been to give our investigations a practical character which would permit their immediate utilization—subject, of course, to the

reservations imposed by the approximate nature and the small number of the investigations already made. It may not be a waste of time to offer certain explanations upon this subject. To build and equip a channel for diverting part of a stream it is necessary to know its slope, its volume, and the speed of its current.

The determination of slope, although it costs something, offers no difficulties. It is done by finding the difference of levels. The division of public surveys in France is engaged in placing in all the Alpine valleys numerous bench marks, by means of which the total slope of different streams can be calculated. This operation, if done once for all, will greatly facilitate the erection of power plants; meanwhile special surveys will have to be made for those plants which it is proposed to erect now.

The flow and volume of the streams, however, can not so easily be determined, but as they constitute the most uncertain and variable elements of hydraulic power, it is important that the fluctuations be measured exactly. Not only should we know the flow at extremely low or extremely high stages, but also the duration of the various intermediate conditions during the year, and the times that they occur. Moreover, we should possess data covering a large number of years in order to determine averages with which to compare extreme fluctuations in very dry or very wet years. French manufacturers, rightly enough, have not been content to utilize a minimum flow; they employ also, during a certain number of months, a portion of the average volume; and it would help them greatly to know, upon the basis of long-continued investigation, the elements that affect the fluctuations in the flow of the streams.

We have not been satisfied, in seeking an exact method of measuring the industrial value of a stream, to make use of such vague expressions as "ordinary low stages," or "ordinary average volumes," or even of other more exact terms like "extreme low-water stage," which, in spite of their scientific precision, do not furnish a practical basis of evaluation. It was suggested at the "white coal" congress that the industrial value of streams not artificially regulated by reservoirs be indicated by two volumes, viz, the normal level below which the stream falls, in an average year, during ten days in the year, and the normal volume below which the stream falls during one hundred and eighty days in the year.

The paper presented to the Grenoble congress on this subject included useful data for the graphic determination of these two normal volumes, and for deducing all the requisite practical conclusions from the curve of average monthly volumes. For more details the reader should consult the original paper,[a] bearing in mind

[a] Tavernier, René, Influence des neiges and des glaciers sur le régime des cours d'eau: Annales Direction de l'hydraulique et des améliorations agricoles, fasc. 32, tome 1, pp. 145–153.

that the determination of normal volumes by either of the methods indicated is based on a knowledge of the average daily flow deduced from hydrometric readings by the aid of a formula specially designed to determine the coefficients needed.

This method of estimating hydraulic forces employs only hydrometric observations and measurements. It does not make use of rain measurements, geologic and glaciologic data, etc., although such studies are proposed, and it is evident that great practical interest attaches to the determination of the different elements that affect stream flow in each basin and of the extent to which they contribute to permanency in the volume of the stream. When these studies have been made we shall be in a position to understand the original causes of those variations which fix and limit the amount of hydraulic power; and in the course of time we shall discover rules which will permit us to use a simple substitute for the direct and always very laborious method of measuring the flow of water.

After a period of active investigations, which shall take up in turn the different mountainous regions, the corps can be gradually reduced to a single central bureau, which shall collate and publish annually the results of the observations made, and revise periodically the general inventory of hydraulic force.

Annual publication of results.—The annual publication of observations, measurements, hydrologic researches, etc., should be regarded as essential, for this will bring to the knowledge of persons and communities who contemplate utilizing the streams a collection of facts of continually increasing interest.

Having in mind these general considerations, we have been led to divide this report on the work of the bureau into several chapters and appendices, which treat each special topic separately, as follows:

Chapter II.—Stations for gaging volumes of water.
Chapter III.—Measurement of rainfall and snow.
Chapter IV.—Description of drainage basins.
Chapter V.—Surveying.
Chapter VI.—Publications.

Moreover, the appendices contain a number of documents concerning various special questions, such as measuring instruments, the first tentative census of hydraulic force, the organization of this work abroad, the theory of volume measurements in streams with changeable beds, typical formulas, photographs of various instruments and appliances, etc.

COMMITTEE OF SCIENTIFIC INVESTIGATION.

By a decree of March 31, 1905, a committee composed of scientific agriculturists, scientists, and engineers was created in the ministry of agriculture as a part of the division of hydraulics and agricultural

improvements to make a study of the various questions of interest to the bureaus in this division. A second decree of December 26, 1905, increased the membership of this committee from 14 to 24 and widened the scope of questions to be studied.

Some of these questions are allied to the subjects treated in this paper, such as the general geologic and statistical study of underground streams, surveys of river profiles, the experimental determination of the value of coefficients used in the formulas for the volume of canals, the study of glaciers, and the study of rainfall and snow.

LAWS AND REGULATIONS FOR REFORMING SYSTEM OF LICENSES AND PERMITS FOR HYDRAULIC POWER PLANTS.

The French regulations take cognizance of two kinds of streams—(1) rivers that are navigable neither for vessels nor for rafts, over which the French minister of agriculture exercises certain police powers and in which the riparian landowners possess certain rights; (2) streams that are navigable by vessels or rafts, which lie within the public domain and which are administered by the minister of public works.

It should be added that the conduits used for the transmission of electric power, which constitute an essential part of hydraulic distributing plants, are placed mainly under the control of the minister of public works.

The report of 1900, referred to on page 12, attracted the attention of the French Government to the insufficiency of the existing legislation on the evolution of the new "white coal" industry, and the minister of public works and the minister of agriculture prepared a bill which they presented to the Chamber of Deputies July 6, 1900. The principal object of this bill was to make all hydraulic power plants of more than 200 horsepower so-called "public" plants, and under its provisions large plants for the industrial utilization of streams could be built only after a license had been obtained for a limited period by petitioners considered to be the best among those seeking this privilege; that is to say, the petitioners who offered the greatest advantages to the community.

The bill of 1900, which guaranteed to the nation the control of all large hydraulic power plants and retained for the Government complete control over the future development of the various public utilities, aroused vigorous protest from manufacturers, who wished these plants to retain the character of purely private enterprises, and, above all, from certain intermediaries, who, having speculated in future riparian rights, were threatened with the entire loss of their possible profits if these large plants acquired the character of "public" concerns.

The opponents to the bill had in mind mainly those streams navigable by neither vessels nor rafts, along which property owners enjoyed certain rights. They succeeded, in 1903, in obtaining consideration of a new plan for revising the existing laws, a plan which had reference exclusively to streams of this character. A bill was proposed on behalf of the Government, January 15, 1904, by M. Mougeot, minister of agriculture. During several sessions of the legislature this bill was investigated and resulted in a report presented to the Chamber of Deputies on February 21, 1908, by M. Lebrun.[a]

Another proposed law, relative to the establishment of power plants on watercourses navigable by boats or rafts, submitted by the minister of public works, has been reported on by M. Baudin[b] to a competent committee of the Chamber of Deputies.

In Italy, after extended controversy, and after a series of laws had been proposed and rejected, there was presented to the Senate on December 15, 1908, a simple text of law providing for cooperation between the ministers of the interior, agriculture, and commerce and labor.

In Switzerland several Cantons have, since 1899, modified their legislation. These modifications, together with the results of exploitation of the principal hydro-electric installations, were discussed in 1906[c] by M. Reuss and M. Cordier. The discussion gave special consideration to the new law of the Canton of Berne, which in 1906 was still in process of revision. Subsequently this process was completed and on May 26, 1907, the law was submitted to popular vote and approved.

Without going into the details of the controversies to which this long discussion of legislative reforms has given rise, it may be useful to explain in the most general terms the nature of the conflict which has arisen between manufacturers and engineers.[d]

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[a] Portions of this report, together with proposed law, appears on pp. 74–85.

[b] Portions of this report, together with the proposed law, appears on pp. 85–92.

[c] Annales de l'hydraulique et des améliorations agricoles, fasc. 34, pp. 189–308.

[d] References to these discussions appear in the following papers:

Les forces hydrauliques des Alpes—leur rôle économique, leur avenir. Rapport présenté à la Société d'économie politique de Lyon, par René Tavernier, ingénieur en chef des ponts et chaussées.

Les grandes forces hydrauliques des Alpes. Rapport présenté à la Société d'études économiques de la Loire, par M. Tavernier.

La houille blanche. Discussion du rapport précédent.

L'utilisation des chutes d'eau dans les Alpes françaises, par M. René Tavernier. Conférence à la Société des ingénieurs civils de la houille blanche, Grenoble, 1902.

Influence des neiges et des glaciers sur le régime des cours d'eau, par M. René Tavernier. Conférence faite au Congrès de la houille blanche, Grenoble, 1902.

Etude hydrologique du bassin de montagne, par M. R. de la Brosse, ingénieur en chef des ponts et chaussées. Conférence faite au Congrès de la houille blanche, Grenoble, 1902.

Législation des chutes d'eau, par M. Ch. Pinot, ancien ingénieur des ponts et chaussées.

De l'utilisation des forces hydrauliques. Études des modifications à apporter à la législation existante. Société d'études législatives, Nos. 1, 2, 3, et 4.

Etude de géographie humaine. L'irrigation. Ses conditions géographiques, ses modes et son organisation dans la péninsule et dans l'Afrique du Nord, par M. Jean Brunhes. Compte-rendu par M. René Tavernier. (Annales des Ponts et Chaussées, 1903, 1er trimestre.)

La richesse du Rhône et son utilisation. Rapport présenté à la Société d'économie politique de Lyon, par M. René Tavernier.

The manufacturers argued as follows:

We provide, on most favorable terms, the power needed by important public utilities. The greater the liberty accorded to us the better we will perform this task, for then it will be easier for us to bring together a large number of power-producing plants, which supplement each other in supplying the public utilities, whose needs are both intermittent and exacting.

To this the engineers made the following answer:

This plan is an excellent one, and entirely in conformity with the economic needs of the "white coal" industry; but, if the underlying principle is carried to its ultimate consequences, as must happen sooner or later, it will lead inevitably to a monopoly in each region, or perhaps to a national monopoly.

Possibly large-scale industries might be able, at least in the beginning and as long as there are still any waterfalls to be utilized, to get along in spite of this monopoly, although it seems singularly dangerous to place forever in the hands of a few persons the control of what is in reality bound to become a raw material for all industries, large or small. A small plant, inevitably tributary to the monopoly which distributes power in its particular region, as well as public utilities like illumination, transportation, and irrigation, all of which are necessarily localized, would manifestly be in no position to discuss the prices asked for furnishing power, when this power is furnished by the "white coal" trust. There can be no doubt that the monopolistic exploitation of this source of power, if completely unhampered, will be able to provide private concerns, as well as public utilities, with the energy needed at the lowest price. It must be asked, however, to what extent will these "masters of the market" be disposed to share with their obligatory customers the savings which they effect in the production of power. The experience of the past furnishes an answer to this question. If we judge all the old practices of gas companies, adhered to until electricity became a competitor, the producers who enjoy a monopoly have heretofore scarcely ever applied rational methods of fixing charges by lowering prices to those who are unable to pay high prices while at the same time charging higher rates to other consumers. Almost always they have preferred, whenever they were given the choice, to make their profits by selling small quantities at high prices rather than by selling large quantities at small prices. It is, of course, possible that the concerns for the distribution of "white coal" power will constitute a happy novelty, and that they will understand their own interests better than the gas companies formerly understood theirs. No one, however, can regard as superfluous the methods by which the proper branches of the Government may constrain a monopolistic corporation producing hydro-electric power to adopt a policy of management which will insure the greatest advantage to the business community at large.

At the present time none of the bills concerning the establishment of hydraulic power plants have been passed. The Government is therefore obliged to carry on this work upon the basis of existing law. We shall indicate in the following paragraphs what the minister of agriculture has been able to do in certain special cases in regard to irrigation.

With regard to the means for transporting electricity, however, very minute regulations have been enacted. The law of June 15, 1906, has been followed by several decrees governing the details of their enforcement. The principal decrees are the following: That of February 7, 1907, creating a permanent governing committee on electricity; that of October 17, 1907, organizing the supervision of power-distributing plants; that of April 3, 1908, supplementing the fundamental features of the law of June 15, 1906; that of August 20, 1908, providing for a standard set of specifications.

The organization for supervising the electric transmission, dealing with technical questions affecting public security rather than with the commercial problem of lowering prices, is of too recent date to justify any conclusions with regard to its possible advantageous effects on irrigation in particular.

SPECIAL STUDIES MADE BY MINISTER OF AGRICULTURE.

The possibility of using the hydro-electric power for irrigation comes up in a peculiar form in the valley of the Rhone, in all the lateral valleys bordering on the Alps, and in the southwestern parts of France, which are watered by streams rising in the Pyrenees.

The regimen of streams flowing from the Pyrenees is influenced by numerous lakes, whose utilization has been systematically planned by the minister of agriculture for a number of years. It is evident that these works, originally planned for the specific purpose of reinforcing the supply of water for the streams flowing out of the tableland of Lannemezan, will also have a beneficial influence on the hydraulic power systems of the valleys that are concerned. The lakes are situated at very high altitudes. Their utilization will create intermittent power, which at certain times may be valuable for irrigation. If the agricultural department will not use it directly, it will at least obtain from those who profit by it a compensation which can not be better used than for the extension of irrigation.

In the basin of the Durance the problem of reservoirs is no less interesting than in the Pyrenees, but its solution is more difficult. Sites for reservoirs of large capacity have long been found and examined on the Durance itself where it joins the Ubaye, as well as at different points in Verdon. Such reservoirs could be used to

counteract the disastrous shortages of water experienced in some years by the large irrigation channels supplied by the Bassa-Durance. It is to be hoped that these reservoirs will soon be constructed. Then the Government, which will reinforce by large reserve supplies of water the hydraulic system of the Durance, the main source of power for the entire southeastern part of France, will be in a position to obtain at low prices from the power-distributing companies who profit by this state of affairs the power needed for irrigation.

Nowadays the system of licenses still in vogue on streams included in the public domain (the Durance is classed as navigable by rafts throughout most of its length, from Embrun to the Rhone) enables the division of agricultural hydraulics to obtain from the motive power of the lower Durance large quantities of hydro-electric power taken at the generating plant for very low prices, varying according to the periods of delivery from 0.01 to 0.015 franc (2 to 3 mills) per kilowatt-hour.

One important question which is now being studied will provide an opportunity for the bureaus connected with the division of agricultural hydraulics to deal adequately with the question of furnishing at low prices the power needed to pump water for irrigation. The question arose in connection with a large undertaking to irrigate the low plains situated on the right bank of the Rhone near Nimes and Montpellier. In 1847 Aristide Dumont, engineer of bridges and roads, first suggested diverting from the Rhone 25 cubic meters (883 cubic feet) a second for irrigation.

After numerous modifications the programme finally adopted in 1897 consisted in building three independent diverting channels discharging a total of 1,660 cubic feet (47 cubic meters) of water. The total cost was estimated at $37,600,000 (188,000,000 francs). The plan was to be carried out as soon as there were enough pledges for the irrigation to require a total of 1,060 cubic feet (30 cubic meters) discharge. The water was to be sold to the cities at a continuous flow, at the rate of 1,000 francs per liter per second,[a] and for watering purposes in intermittent supply at the price of 63.50 francs per liter per second ($1.50 per million gallons at about 50 cents per acre-foot).

This vast undertaking has stirred up public opinion for fifty years and has given rise to sharp controversies which may be found in the report of the writer on "The wealth of the Rhone and its utilization."

There were two parties to the debate, one side representing the interests of navigation and the other the farming interests. The

[a] Equivalent to about $5,700 per second-foot of constant flow, or about $8 per acre-foot per year, or about $24 per million gallons per year.

failure to carry out successfully the programme of 1897, moreover, is due less to the opposition which it encountered than to the impossibility of obtaining the number of pledged subscribers for the use of the water that was considered indispensable for the successful operation of the enterprise.

To-day it seems that, thanks to the installation of hydraulic power plants, these old quarrels are about to die out. The question of the Rhone irrigation channels, stirred up by the dolorous and disturbing crisis in wine production which is now being felt by the southern part of France, is being so modified as to bring us nearer to a solution that will harmonize rather than accentuate divergent interests.

A recent decision of the minister of agriculture has intrusted the writer of this paper with the task of devising an irrigation system based on the pumping of water taken from the lower Rhone. The most important part of this investigation will consist in finding how to furnish power at the lowest price for the pumping stations, either by compelling the future holders of licenses for hydraulic plants to concede specially low terms, as has already been accomplished in connection with the motive-power syndicate of the lower Durance, or, if it should prove necessary, to elaborate a complete plan for the erection of an entirely new series of plants for furnishing power to all the concerns that might need it in the region under consideration.

CONCLUSION.

The United States of America, at least in the opinion of those who, like myself, are yet unfamilar with the country, is par excellence the land of great business enterprises, because of wonderful personal initiative, the power of large masses of capital, and the intensity of local life due to the economic independence of the several States. I am sure that these elements will play an important part in the exploitation of the hydraulic wealth upon which is so largely dependent the development of such regions as the one in which this congress is being held [Albuquerque, N. Mex.]. But I have also noted, with equal gratification, the powerful cooperation in the development of water power that is being provided by the Federal Government through the Departments of the Interior and of Agriculture, without which isolated and independent enterprises would run a great risk of failure. The marvelous work of the Geological Survey and of the Reclamation Service is too widely known to require any word of praise from me at this time and place. But I wish to draw one inference from this general phenomenon of the increasing intervention of the central Government. We appear to be gradually recognizing more and more fully that hydraulic wealth is

a collective wealth liable to be wantonly wasted if it is not used co-operatively. If water, which has so long divided mankind, seems now about to bring them together for the common good; if there is to be harmony between interests which long have been antagonistic—all of which miracle is to be wrought by the fairy named Electricity—it will everywhere be necessary for a final tribunal to intervene on behalf of such harmony in the interest of the community, regardless of administrative and political boundaries, with which hydrologic phenomena have no concern.

A profound consciousness of this new sort of interdependence has given rise to the measures that are being taken in France by the minister of agriculture to enable irrigation to benefit by the utilization of hydraulic energy.

CHAPTER III.

FRENCH AND FOREIGN LEGISLATION RELATIVE TO THE DEVELOPMENT OF WATER POWERS.[a]

By René Tavernier.

PRACTICAL UTILITY OF THE STUDY.

It is not purposed to discuss water-power legislation in France, Italy, and Switzerland from the point of view of the lawyer or the historian. The simplest analysis of the voluminous treatises that have been written on the subject in the three countries would require too extended space. Most of the authors of such treatises are lawyers who have been inclined to study the past; when considering the future they have endeavored to preserve the old traditions, even in the most modern application. Practical men, on the other hand, who desire a quicker development of the industry, try to accommodate themselves as well as possible to the antiquated laws rather than endeavor to institute a reform and have the laws corrected, dreading the intervention of the Government and fearing to avail themselves of its almost indispensable cooperation, lest they provoke undesired interference.

It is difficult to imagine a greater disparity than exists between the character and scope of the present French legislation and the actual state of affairs with reference to water-power development. The necessity for bringing these laws into harmony with present conditions has been generally recognized, and it has been shown that the requirements imposed by these ancient laws are insecure and transitory. We need not enter into an investigation of Roman or feudal law to find the origin of the present law with reference to watercourses. It will suffice to state that in France watercourses that are navigable for neither ships nor rafts belong to the owners of adjacent lands; in Switzerland control is retained by the Cantons and communes;[b] and in Italy the waters are public property, concessions for development being issued by the Government.

[a] A translation of chapter 3 of M. Tavernier's report, made in 1900, "Les forces hydrauliques des Alpes en France," referred to on p. 12.

[b] The Canton of Switzerland corresponds to the State of the United States; the commune corresponds to the county. Since this report was written the control has passed to the Federal Government.

Before the introduction of electricity water powers were employed only on small tracts of land bordering the watercourses, but recent progress in electric transmission has made it possible to extend their use over wide areas. Whereas formerly an application by a riparian owner for a license to use water, either for irrigation or for a mill, meant only that he would use the water for specific purposes on his own property, now the use of water power has entered a new field and new financial benefits are derived from it. Consequently new laws and regulations have become a necessity.

FRENCH LEGISLATION.

LAWS AND REGULATIONS IN FORCE.

Applications for the establishment of power plants along nonnavigable watercourses in France were, by circulars of October 23, 1851, December 26, 1884, and March 2, 1898, made subject to certain regulations. More recently the administration of watercourses has been made the subject of a law, promulgated April 8, 1898, article 12 of which anticipates the enactment of a new law providing for broader public control than that afforded by the circulars mentioned above. It should be stated, in connection with subsequent quotations of certain passages from the work of M. Delbet, that the legislation of 1898 has not settled the question of the ownership of power privileges and has not brought thereinto any new principle. The ownership of the river beds by the riparian proprietors is conceded, and there is no separation of the power sites from the watercourses in general.

This law, promulgated after consideration of the matter during a period covering nearly a century, shows a very plain disregard of modern needs and requirements. It is said that the Chamber of Deputies wished explicitly to give to the riparian owners on the watercourses the control of power privileges. To this the Senate was opposed. In this connection, M. Delbet, deputy, in his report of July 12, 1897, says:

> The proposed law does not deal directly with the ownership of waterfalls not actually operated. The commission of the Chamber in 1888 wanted especially to prevent any encroachment by the Government on the rights of private property and the arbitrary disposal thereof. The commission thought that a special law covering this point could be framed after its utility had been proven; but, as it was of importance not to retard any longer the vote on this paragraph of the rural code, consideration of this matter of comparatively small importance was omitted, in order to avoid a new discussion that probably would have resulted in the failure of the entire measure through nonconcurrence of the Senate.

It seems impossible to modify the rules defining government intervention in matters of power-plant regulation without creating a

new law. Such intervention, if reduced to a minimum, would fail to effect necessary reforms.

JURISPRUDENCE.

The Government does not intervene in an ordinary disagreement unless it becomes necessary to protect the riparian owners from damage to or infringement of their water rights. To make such intervention perfectly legal, broader powers should be assumed. Indemnity for private damages and the defense of private rights are adjudicated in the lower courts, except where the rights of third parties are involved. In spite of many commentaries, circulars, and decrees specifying the scope and application of the law, the limit of administrative power has always been most uncertain. Engineers are greatly embarrassed by the opposition encountered in their work. They frequently have to act as intermediaries between opposing parties for the purpose of settling disputes out of court. The Government does not, as a general rule, concern itself with the verification of the petitioner's claim that he owns the necessary tract of land; it does not even specify the amount of water permitted to be withdrawn. Consequently the privileges actually granted may be utilized only in part, or not at all, and the nation has no right to interfere. Neither does the Government concern itself with isolated claims for damages inflicted on downstream owners by upstream diversions. There results, in effect, confiscation of the property rights of the greater number of people for the benefit of the fewer, and this is made more serious by the fact that the right, as created under the water regulation, is perpetual and without a forfeiture clause.

Few real difficulties are encountered with such a law so long as it applies to the short diversions established by owners of rights within their own property. The right to a waterfall created under this law is, in effect, an extension of the general right of ownership in the water and, like this general right, it is perpetual and absolute. It is singular that such an extension of the administrative permit appeared necessary. It would have been more logical to vest the ownership of the waterfalls specifically in the owners of the banks, as was at first intended by the legislature of 1898. M. Picard explains why this was not done.[a] The reasons were as follows: First, the slope of the river bed between the limits of the property of a single owner is not, in most places, sufficient for the development of power necessary in the operation of a plant of important size. Furthermore, it would be very difficult to induce the bank owners to combine their partial powers and thereby create a common power susceptible of development and utilization to the profit of the whole

[a] Traité des eaux, vol. 1, p. 250.

community or of one of the members thereof. The resistance of one riparian owner would be sufficient to render the resource unavailable, to the great detriment of the public interest.

Accordingly, for the reasons set forth, the legislature of 1898 explicitly refused in all cases to unite the ownership of the water with the ownership of the banks. And so, legally, under the new law, the actual water itself is nonexistent (res nullius), although, as in the past, it is subject to private appropriation by the person who first makes application for an administrative permit to make beneficial use thereof.

DEFECTS OF THE PRESENT LAW.

Under present conditions the difficulties encountered in the development of hydro-electric plants are almost intolerable. An installation of such character generally involves the diversion of the total low-water flow of a river for several miles along its course. It affects the interests of hundreds of persons, including the owners of lands crossed by conduits or occupied by the plant as well as the owners of the river banks. The founders of the great hydro-electric power plants in Isère and Savoie did not at first apply for government license; this they did after they had quieted all objections by procuring the necessary bills of sale, contracts, and other legal documents. But this practice is no longer effective, because the landowners are becoming conscious of the value of the water powers and are less easily persuaded to part with their rights than formerly; also because the benefits that have been realized have given rise to an outburst of speculation. A new class of speculators, properly called obstructionists, has appeared. These people, by purchasing a few lots at different places, control the situation and completely prevent water-power development unless the promoting interests accept their terms. As a result of this, it frequently happens that power sites of first choice have to be abandoned for less convenient but more easily attainable ones. If one considers the enormous capital invested in electro-chemical and electro-metallurgical industries; if one knows, on the other hand, the importance of transmission to the industries which would, without it, be compelled to locate at great distances from their supply of raw material and far from their market; and if, finally, one takes account of recent happenings along this line, he can not but perceive that there exists a condition of chaos and dissatisfaction. Such practices are destructive of public confidence, public morals, and general public economy. Considered even from the standpoint of private initiative, they are as pernicious as are the laws that make them possible, but when public interest and the duty of

the nation are considered the reproaches that may be cast on the law are very forcible.

The Government should intervene in the interest of public safety. It should regulate the construction and operation of all reservoirs and conduits. The failure of such structures, exposed as they frequently are to high pressures induced by great hydraulic heads, is liable to cause great loss of life and destruction of property. A second reason for government intervention is that, before granting a new concession and thereby creating a new right, which covers all the previous rights but which constitutes a sort of special right, the Government should satisfy itself that the applicant for concession, whom the outsider is powerless to oppose, is, in reality, capable of installing and operating the prospective works. It is a question of public morals and also one of general economy. A third reason for government intervention is that it is highly desirable that the industry which has acquired a right by purchase from intermediaries, who sell to their advantage a right to water power created by administrative act, shall be protected against the possibility that the title to the property shall be clouded by the appearance of some accidentally forgotten owner, who will create disturbance by subsequently selling his interest to some adversely disposed person. This does not apply to small developments but to hydro-electric power plants which represent a large outlay of capital. It is often the case that, at an unexpected moment—thanks, it is said, to the connivance of the administration—the integrity of such an investment is compromised by the appearance of old claims. From considerations of general economy and of public interest it is intolerable that the capitalization of so valuable a natural resource shall be held in check by so many obstructions that in certain cases even the appurtenant works necessary to the completion of the development can not be established, in default of the necessary ground.

To avoid all these abuses without modifying legislation it would be necessary for the administrative authorities to subject the proposed projects to a minute examination, to satisfy themselves that all necessary preliminary arrangements are made, all necessary lands purchased, and all rights acquired. It is believed that even such precautions would not be entirely sufficient, because even where all such provisions were fully complied with, the administration would still be without power under existing law to force the grantee of the right to utilize the water power to its full capacity and in a rational manner. The existing law does not fix the amount of water to be used, and it makes no stipulations except a time limit placed on the construction of works and provides no forfeiture for nonoperation of the works and nonutilization of the water. In other words, the adminis-

tration creates an unlimited and exclusive right to a resource, without even imposing on the grantee the obligation of using it and without giving to him the means of so doing, if he meets with opposition from outside parties.

In all the preceding critical analysis, the intervention of the nation has been regarded solely from considerations of the security of public interest in respect to water rights and of the principle that the nation should not abandon control of the natural resources without at least imposing the obligation of their utilization. It is undeniable that on all these points the laws in force do not permit the administration to exercise such absolute control as we have pointed out.

The method of utilizing water power will now be considered. Under existing law a holder of a concession for light and traction may endeavor to acquire also a concession for a power plant and for some industrial establishment. As the interests of two such persons in the same region may clash, it may occur that both parties are defeated in their purposes, or that one is favored at the expense of the other. Vast public interests may be damaged in this way, and work of the greatest importance may be frustrated. There is no legislation at present to remedy this condition. In fact, the intermediaries who exploited the first water powers in the French Alps were not concerned with enterprises of public interest, and it will be recognized that, on account of the poverty of the people in the region in which they are located, such enterprises can not be immediately productive of the greatest benefits.

In examining the list, set forth in statistical tables, of the large hydro-electric developments recently established in France, in Switzerland, and in Italy, one can not but be impressed with the great and characteristic differences in the uses to which water power is put. In France the great developments are largely private and are devoted to electro-chemical and electro-metallurgical industries. In Switzerland and Italy the developments are great public enterprises engaged in the transmission and distribution of power in the open market for traction and other purposes. This is due, no doubt, in part, to the fact that the French Alps have a smaller population and fewer industries than have the Swiss and Italian Alps; and in part also to the insufficiency of French legislation.

PROPOSED REFORMS.

The difficulties encountered under existing law, on the one hand by those who are trying to operate large water powers and on the other by the government representatives charged with the application of apparently inapplicable and insufficient laws, having been summarized, it is now incumbent on us to show what reforms are proposed.

The first and principal reform should consist of the substitution of concessions[a] or franchises in place of the present license or mere permission. These concessions should be limited to a specified time and to a specified hydraulic power. They should include the usual clauses of redemption and forfeiture, although they need not necessarily confer upon the grantee the right of expropriation, resort to which in each case should be determined by its effect on the public interests, present and future.

The granting of concessions only for the large enterprises and the continuing to issue permits for the smaller powers will quiet the apprehensions of those who persist in considering the water powers as private property, or at least as a natural extension of private property. Such owners say, "If a fall is entirely on my property, if I am the owner of both banks, why should the Government oppose my using the water at my convenience, provided I return it at the boundary of my grounds, in compliance with article 644 of the civil code? If a number of owners should unite and transfer their rights to an individual, how could the Government refuse to that individual the same rights it grants to the original owners? [Referring to simple permits.] Is it not extraordinary that it should claim to have the right to enter upon private property and place there, for the development of power, a concessionnaire of its own choice?"

The premises upon which these arguments are based are incorrect. The proprietor of both banks of a stream is not refused the right to develop the water power; on the contrary, he is denied the right of not using it. In fact, in the development of water powers, as in all other enterprises susceptible of being considered public utilities, the private citizen is freely allowed to realize a profit from and on his possessions. It is not intended to crowd out the little owner and to prevent him from using the small privileges for his small enterprises. It appears necessary to reconcile the opposing views and to preserve, in general, the system of granting permits for water powers of less than 200 horsepower, while the larger powers, which are destined to play a great part in the public economy, shall be regulated under concession, with an accompanying declaration of public utility. A special precaution should be taken in every case; the concessionnaire ought to prove the general utility of his enterprise, and the smaller mills should not be permitted to interfere with large developments and thus diminish their usefulness to the public. The best plan would be to permit the small mill to exist by the side of the large plant and to have returned to it, in the form of power, the equivalent of that which the larger plant takes in the form of water.

[a] The French word concession seems by this and subsequent context to be identical with what is commonly known in this country as a lease. There may, however, be a slight difference between the two. Therefore the former term will be used in subsequent pages.—M. O. L.

PRINCIPLES PROPOSED FOR BASIS OF NEW LEGISLATION.

The ideal solution consists in permitting all the interests, private as well as public, to develop power, and in considering according to their respective merits several applicants who seek to obtain concession of the same power site. Such is the policy upon which the following general principles are based:

1. All the various lines of water-power utilization must be facilitated and encouraged simultaneously, because the water powers are concentrated at certain points in such enormous quantities that there is no risk of their speedy exhaustion; further, because, for technical and economic reasons, it is of the greatest advantage to distribute the power produced among the greatest possible number of uses.

2. The engineers of the Government, of the provinces, and of the counties, as well as those representing private interests, must be free, and even encouraged in special cases, to make studies and propose methods for making the best use of water power.

3. The power of concession must belong to the State [that is, the National Government], which alone is able to combine all available information and to settle difficulties arising among opposing interests. Such power should be exercised irrespective of all financial influences, in the sole effort to derive from the exploitation of public resources the greatest possible amount of benefit. When there is no general public interest that would be damaged thereby, concessions shall be granted, with or without a clause of retrocession, in the following order of preference: First, to the province; second, to the county; and third, to a company making application therefor.

4. The duration of a concession shall be limited to the shortest possible term, in order that any mistakes or defects in the regulations may be corrected and that changes may be made to conform to changes in conditions. Among such possible modifications, the most important will undoubtedly be the adoption of electric traction by large railway systems.

5. The acknowledgment of special rights of any person or privileges in water powers should be guarded against. Neither the exclusive right, granted provisionally in France to riparian owners or to intermediaries to whom such owners have conceded their rights, nor the right of prior application, recognized in Italy, subject only to the higher interest of the Government, is an acceptable standard. The highest duty of the Government in the matter of water power, as in the matter of railroads and street railways, is to follow that course which will give to the public in general, and especially to the neighboring populations, the greatest advantages.

The chief characteristics of such legislation as we believe desirable having been outlined, it now remains for us to study the matter

in detail and to formulate the precise language. Before doing so, it will be useful to analyze and set forth certain characteristic points in Italian and Swiss legislation.

ITALIAN LEGISLATION.

CLASSIFICATION OF WATERS.

Industrial diversions, like those for agricultural purposes, are regulated in Italy by the organic law of August 10, 1884, regulating the diversion of public waters.[a]

First let us consider the designation "public waters." Are all the natural watercourses, even the very small ones, covered by this law? This appears not to be so, because article 25 provides for a "classification" of the "public waters" of the nation.[b] Nevertheless, it would appear proper that this term should comprehend all large watercourses that are susceptible, by reason of the volume of their waters or the extent of their courses, of serving public purposes. This, of course, includes lakes and watercourses made navigable or improved by national subsidies. Such waters are subject to the control of the sovereign, while the other watercourses come under that of the prefect. There is disagreement among the lawyers as to the classification of "public waters," and also as to the nature and importance of the domain rights of the nation. According to some, the public waters are a part of the public domain; and, according to others, they are a part of the private domain of the nation. (See Pacelli, Francesco, Le acque pubbliche: Report of the commission created by decree of August 16, 1898.)

For the diversion of "public waters" a "concession" from the Government is required, such concession being granted in virtue of the payment of rent (article 1).

DISTINCTION BETWEEN "CONCESSION" AND "AUTHORIZATION."

It is interesting, in connection with article 1, to note a passage from the work of M. Pacelli, cited above, which compares the French and Italian legislation and treats of the distinction to be made between the "authorization" of the French system and the "concession" of the Italian system:

> 140. There has been formulated in France, specifically in the matter of public waters, an important distinction developed in Italy within recent years in an able monograph by Ranelletti—the distinction between a concession and an

[a] A French translation of this law is inserted in the Bulletin de l'hydraulique agricole, pt. 6, p. 126.

[b] The attitude of the Italian administration concerning the execution of this list is set forth in a circular of the minister of public works of February 6, 1888, in which is accepted the theory that very small watercourses are not a part of the public domain.

authorization. The former recognizes the creative function of the nation; it gives to the concessionnaire a new right—a right which he can acquire only by asking for it. The latter recognizes the activity of the nation as a guardian; it consists in removing certain obstacles in the way of private activity; it permits the exercise of a right that existed in substance previous to the application.[a] This distinction was made in France for the purpose of reconciling the civil code with the administrative legislation relative to the waters. It has been explained that the authorization is sufficient for nonnavigable watercourses where the riparian owners have a right of usage in virtue of article 644 of the code of Napoleon, and that a concession is required for navigable watercourses, which are expressly exempted from the provisions of that article. This distinction, accepted almost universally, * * * was applied in Belgium in the law of May 7, 1877, relative to nonnavigable watercourses. * * *

141. In Italy the distinction between concessions and authorizations in the matter of fluvial domain is accepted by those who endeavor to reconcile article 543 of the civil code with the law relative to public works; they contend that a concession is necessary in the case of rivers and torrential bodies of water, and that an authorization is sufficient for the other watercourses of less importance. In my opinion, contending that a complete separation must be maintained between the waters regulated by the civil code and those regulated by administrative laws, the distinction is not applicable in Italy to the matter of public waters. According to my judgment, the fact of being an owner of the banks of a public watercourse, large or small, implies no right of usage, and I contend that article 543 of the code applies merely to small private watercourses. A concession will then always be necessary to vest in an applicant a right of usage, in which he previously had no interest other than the possibility of procuring it by application.

After this theoretical digression, we will now return to the analysis of the law of 1884.

ANALYSIS OF THE LAW OF AUGUST 10, 1884.

The papers of the concession fix the quantity of water to be diverted, the conditions of diversion, withdrawal, use, and restoration of the waters, the rental, etc.; they also stipulate the requisite guaranties in favor of agriculture, industry, or public health. They fix the period within which the water must be diverted and used, under penalty of forfeiture. (Article 4.)

A concession can not be granted for a period in excess of thirty years, but it is renewable in favor of the first concessionnaire for new periods of thirty years unless he, in the opinion of the administration, has attained the purpose for which the concession was granted to him. (Article 5.)

The concessionnaire is at liberty, under certain conditions, to change the purpose and equipment of his plant. (Articles 6 and 7.)

[a] Following that theory, the system of authorizations or permits should not be applied in France to industrial diversions, since the legislature refused expressly to recognize in the riparian owners any right to "the falls of water." We have, on the other hand, long insisted on the inconveniences arising from the creation of a right by means of a simple authorization or permission.

Formal official instructions relative to concessions are regulated by articles 8 and 9. Certain prescriptions relative to security, closing of gates in times of floods, etc., are treated in articles 10, 11, and 12.

If, during the period of the concession, the regimen of the watercourse is changed in the public interest, the nation is not held to any indemnity in favor of the concessionnaire, who in such event has a right merely to a proportionate reduction in or cancellation of rental. (Article 13.)

Article 14 fixes the rental—3 francs (about 55 cents) per horsepower in industrial diversions. Articles 15 to 19 prescribe certain exemptions or certain details of collection of taxes. Articles 20 to 24 establish agreement with other laws.

Article 25 relates to the making up of the "schedules of public waters" previously mentioned.

Articles 26 and 27 relate to the making up of a register of "diversions of public waters," compiled from the "declarations" of interested parties.

Article 28 provides that the details of the execution of the law shall be determined by a public administrative regulation.

PUBLIC ADMINISTRATIVE REGULATION OF NOVEMBER 26, 1893.

In execution of article 28 of the law of August 10, 1884, the first public administrative regulation was promulgated on November 9, 1885; but it quickly became insufficient and was replaced by a more complete and modern regulation November 26, 1893. This new regulation added to the law two new principles which had not previously been recognized and which were rendered necessary by the zeal of speculation brought about by profitable water-power developments—(1) the principle of preference in favor of the first applicant for concession in cases where concurrent applications technically can not coexist (article 8); (2) the principle of the higher rights of the nation, which may, in the consideration of public interest, either oppose an individual application (article 7) or accord the preference to one of the later applications among a number of concurrent applications, in derogation of the principle first established.

CIRCULAR OF JUNE 17, 1898.

The interpretation of these two principles and their application by Gen. Afan de Rivera, minister of public works, in his celebrated circular of June 17, 1898, in which he charged all prefects, engineers, etc., to deny all applications for powers that might be utilized for electric traction on the large railroads, aroused and still arouses lively discussion in the technical and industrial world of Italy. The directors of the Compagnie fermière du grand reseau de l'Adriatique

entered into a vigorous controversy with General De Rivera on certain technical questions in the Nuova Antologia of June 15 and August 1, 1898. They seemed, however, to share his opinion as to the necessity of preventing a monopoly of water powers, in view of the adoption of electric traction, and as to the importance of electric traction for mountain lines with small traffic.

REVISION OF THE LAW OF AUGUST 10, 1884.

In response to various expressions of dissatisfaction a decree of August 16, 1898, named a commission for the purpose of reforming the law of 1884. The terms of this decree are as follows:

(*a*) To establish rules and limitations of concession for diversions of public waters, either for electric traction of railways or for other industrial and agricultural purposes of no less importance in the social economy.

(*b*) To devise administrative regulations for the prevention of speculation and monopolies and changes in the objects of concessions granted.

(*c*) To formulate, in the spirit indicated in *b*, modifications that might desirably be incorporated into the laws and regulations in force.

SCOPE OF THE PROPOSED NEW LAW.

The new text proposed by this commission introduced into the law many of the regulations of 1893 and, more particularly, the two principles already mentioned (pp. 46, 47), which are fully explained and commented on. It modifies, moreover, the competency, nature, and method of renewal of concessions, the determination of rentals, and certain details of administrative procedure, which are of no special interest, except in connection with the Italian administrative organization, which is slightly different from the French.

Below are given explanatory summaries of each of these points:

1. Principle of preference in favor of first applicant. This principle, supported by article 6 of the regulation of 1898, is retained in almost the same terms in article 5 of the proposed law:

> Whenever two or more applications are made, in the prescribed form, for all or a part of the same concession, and the several interests represented can not all be served in common, concession shall be granted to the application first presented.
>
> This rule is subject to derogation when predominating public interests militate in favor of some later application, presented less than a month after the expiration of the term named in the decree of publication of the first application.
>
> The reasons brought forward must be submitted to the examination of the administration and to committees appointed to give advice on applications for concession.

2. Principle of according priority to the interests of the nation. The application of this principle is regulated by article 3 of the proposed law, as follows:

Whenever application is made for concession for a diversion of the first class, consideration thereof shall be preceded by an examination by a permanent special commission, to determine whether, irrespective of the application in hand, any legitimate public interest or any present or future need of the nation interferes with the granting of a concession. This commission is appointed at the beginning of each year, from members of the higher board of public works, of the high committee on tariffs, of representatives, of the high legal counsel of the treasury, and of ministers of public works, of finances, of agriculture, of industry, and of commerce, as well as of the war and navy. If the decision of said commission is favorable, the examination of the application in the regular manner immediately follows. If the decision is unfavorable, the minister of public works shall, after consultation with the higher council and the council of state, render a decree deciding whether the examination of the application shall proceed. By means of such a decree, the minister can, if necessary, ultimately prevent all concessions to individuals in a certain river basin, section, or lake over which he has control.

If, in the interest of a public service, the nation finds it desirable to utilize, or to reserve, in any manner, water powers of one or another class, the competent administration, or a deputy named for that special purpose, shall present a preliminary plan containing a technical exposition of the purposes, nature, object, and utility of the work to be established or of the reservation. This plan shall be submitted by the minister to the permanent special commission aforesaid, and in accordance with its advice and that of the higher board of public works, after consultation with the council of state, he shall decide by special decree the appropriation or reservation of the power privileges demanded for the public service. In case of a favorable decree, all individual demands that can not technically coexist, along with the project or the reservation of the Government, shall be denied, irrespective of the state of advancement of construction.

The decrees of the minister of public works are unassailable, the only recourse against them being that provided by articles 12, 14, and 24 of the law for the council of state.

3. Changes in jurisdiction. According to articles 2 and 3 of the law of 1884, jurisdiction was based on the character of the watercourse. A law was required in the case of a perpetual concession, a royal decree for those relating to lakes, rivers, boundary waters, navigable streams, and watercourses whose embankments and shores are recorded among the hydraulic bodies of the second class, while the prefect decided in all other cases. According to articles 2 and 3 of the proposed law, on the contrary, the jurisdiction depends on the importance of the diversions, which are divided into two classes. The first class, for which a royal decree is necessary, corresponds to the "large diversions," the limits of which were fixed by article 1 of the regulation of 1893, covering specifically all developments of power greater than 200 horsepower. The prefect has jurisdiction over all applications of the second class, except that where the application

concerns a lake, a navigable watercourse, etc., he obtains authority from the minister of public works.

4. Changes in character and conditions of renewal of concessions. The principle of a thirty-year concession, renewable indefinitely in favor of the first concessionnaire, with clauses of forfeiture but without clauses of redemption or return to the nation, is retained in the proposed law as it was laid down by the Italian law, but with certain modifications designed to prevent monopolies or to obviate making it irrevocably binding for all future time.

In order to reduce the chances for monopoly and speculation, article 1 of the proposed law stipulates:

The concessionnaire of a public water diversion can be authorized by the decree of investiture to form either a syndicate or a civil or commercial company for the exploitation of his concession, provided he remains connected with it up to the time of the organization of the company and provided that the organization is effected within a period of six months from the date at which the decree of investiture went into effect. It is forbidden, under penalty of forfeiture, to transfer to a third party a concession for the diversion of public waters in any other manner before such concession shall have been entirely utilized.

The conclusion of the same article contains the following new condition relative to municipal concessions:

Municipalities may reconvey to third parties the exploitation of waters vested in them for the benefit of public service, such as electric lighting, railway traction, and for domestic or hygienic purposes, provided they follow a simple system of reimbursement of expenses of exploitation over and above the interest and amortization of capital used, to the total exclusion of all speculation.

With reference to the duration and the renewal of concessions, it may be observed that perpetual concessions no longer exist. Article 5, the last paragraph only of which is new, is as follows:

ARTICLE 5. Concessions are granted for a period not exceeding thirty years; but at the expiration of that period the concessionnaire has the right to a renewal of the concession for a second period of thirty years, with such modifications as must be made in the conditions of the concession by reason of changes in the premises or regimen of the stream. The renewal of the concession can be refused, if, in the opinion of the administration, the concessionnaire during the preceding thirty years, either through usage or abuse, has not fulfilled the object of the concession. Renewals after the expiration of the second thirty-year period are optional with the nation.

There is an additional article, No. $5\frac{1}{2}$, which contains an entirely new requirement, providing for the alteration of a power development found defective. This article reads as follows:

In order to better utilize watercourses on which concessions have been granted, such concessions may be suspended for certain periods and renewed in favor of new concessionnaires, under condition that the first concessionnaire receive, without cost or risk, a quantity of power or water equivalent to that of his concession, the rentals and other obligations stipulated by the decrees of investiture remaining the same for all concessionnaires.

Finally, article 4 of the proposed law contains a provision, almost identical with a paragraph of article 14 of the regulation of 1893, which is very important in the gradual development of large concessions. It is as follows:

Whenever it shall occur that any concessionnaire can not employ immediately all of the water or all of the power conceded to him, the conceding authority can consent to a progressive development, subject to the uniform payment of an equitable rent. The different periods of progressive utilization shall be fixed in the decree of concession, as well as the quantity of water or power that may be utilized in each period and the corresponding rental. Decrees which do not contain such limitations are rendered void and must be renewed.

Decrees of concession shall define, in conformity with the regulations adopted, the periods within which the concessionnaire must fulfill the various conditions of his concession, whether fixed or gradual, up to the complete utilization of the water to be diverted. If these periods are exceeded without sufficient cause, the administration has the privilege of declaring the concession forfeited or of restricting the quantity of water or power actually utilized.

These periods can not be extended, except for the enlargement of capacity of the development, without a renewal of the application and the issue of new instructions.

5. Changes in assessment of rentals. The proposed new law preserves the rental of 3 francs (about 55 cents) per horsepower, fixed by law of 1884; but it introduces, in connection with long-distance transmission, a principle of reduction, which is in harmony with the views expressed by the congress of electricians at Turin and which will, without doubt, be somewhat unacceptable to the populations of the valleys in which the powers are located because it will favor long-distance transmission of power, to the detriment of local interests. The basis of the reduction is as follows:

For power transmitted by means of electricity to distances greater than 10 kilometers (about 6 miles) there is granted upon the annual rental of 3 francs per horsepower, a reduction calculated by multiplying the square of the distance expressed in kilometers by a fixed coefficient of 0.001. In no case shall the rental be reduced to less than one-half of 1 franc per horsepower.

Under this formula the minimum reduction, that is to 0.50 franc, will be attained in transmission over 50 kilometers (about 31 miles).

6. Power of expropriation. Examination of the law of 1884 and its various provisions has enabled us to review the fundamental principles of Italian legislation as well as to compare it with French legislation. In order to complete this exposition and to set forth all the elements involved in an intelligent comparison, some supplementary remarks will be required.

Although in Italy the more formal concession takes the place of the French permit and water regulations, the numerous formalities thereof, which are fixed with such detail by the regulation of 1893, apparently do not entail longer delays after the filing of the application than does the French procedure. On the contrary, the Italian

regulation of 1893 permits an official examination more rapid, more compliant, and at the same time infinitely more complete, and it not only covers considerations of drainage and irrigation, but also advantages and disadvantages of the enterprise. An application is not accepted and examined unless it is accompanied by plans and specifications by which classification (provided by a supplement to the regulations for large diversions or diversions of the first class, article 3 of the regulations) may be simplified. The applications, together with accompanying explanatory documents, are, after examination by the provincial deputies, subjected to individual examination for fifteen days by a prefectoral commission which shall fix within the same period the time for visiting the power site. These formalities accomplished, the administration can act on the report of the civil engineers.

If there intervenes no consideration of the higher interests of the nation, the decision can be rapid; but, in accordance with the circular of Gen. Afan de Rivera, all applications must be first examined in their relations to the present or future needs of the services of the nation.

We have indicated above, in the citation of article 3 of the proposed law, that in accordance with that article the preliminary examination must be vested in a mixed permanent commission, without reference to the advice of the various ministers. This is a procedure burdened with complications and delays, which has occasioned many complaints and provoked much uncertainty.

One real advantage of the Italian legislation is that, while it protects specifically the interests of third parties by granting them all opportunity to be heard and by providing for all needful examinations, it grants to the concessionnaires the right of availing themselves of the law of June 25, 1865, concerning expropriation, and even stipulates that the individual inquiry shall serve equally for the declaration of public utility of the enterprise (last paragraphs of article 1 of the regulation of November 26, 1893). In conclusion, it is remarkable that the number of cases in which it has been necessary to have recourse to expropriation has been very small.

SWISS LEGISLATION.

Each of the twenty-five Cantons of Switzerland has its special legislation or simple jurisdiction over the waters within its boundaries, and the cantonal authorities, without interference from the Federal Government, regulate the use of water powers in their own way and in accordance with divers principles. To examine and compare them all would be an extremely laborious task. Fortunately, at a recent period and in connection with circumstances that we will explain,

this work of inquiry, compilation, and comparison has already been undertaken and well carried out under the care of the federal administration.

INQUIRY INTO EXPEDIENCY OF WATER-POWER REFORMS.

In April, 1891, the Swiss society "Frei Land" issued a petition demanding the insertion of the following clause in the Federal Constitution:

All the water powers of Switzerland not yet utilized are the property of the Confederation. A federal law shall regulate all that concerns the application of this resource and the distribution of the net benefit produced by it.

In order to procure information concerning the value of so radical a proposition, the Swiss Federal Council, by circular of September 8, 1891, began an inquiry in all the Cantons concerning the extent and importance of the water powers, the existing laws and procedure with reference thereto, and the expediency of the reform proposed by the Frei Land Society. It consulted at the same time various technical and industrial authorities, and finally directed A. Jegher, an engineer of Zurich, to study all the data assembled as a result of such inquiry and to formulate therefrom practical deductions.

The conclusions at which the Federal Council arrived and which it embodied in a report of June 4, 1894, approved by the Federal Assembly April 4, 1895, are as follows:

1. The great majority of Cantons which possess and exercise the right of sovereignty over their watercourses and which often derive direct income therefrom are not disposed to renounce that right of sovereignty.

2. In general, the public interest in this matter is safeguarded by the Cantons according to the importance in each case.

3. The transfer to the Confederation of the right of sovereignty and of administration over water rights would not afford any advantage to the country and would not present any source of new revenue, either to the Confederation or to the Cantons.

4. The possibility of availing itself of the water powers in the future could very easily be reserved to the nation by cantonal legislation.

5. In general, the cantonal authorities are better able than the Federal Government to see to the highest development and utilization of water powers, both from an economic point of view and from that of public and industrial interests.

6. The importance, sometimes limited, of the object in question and the securing of a rational use of the various falls, which is often difficult, require the cooperation of the cantonal authorities specially qualified to protect the development of the local trades and industries of the Cantons.

The Federal Council and the Federal Assembly, by concurrence in their conclusions, were of the opinion that for the above reasons the petition of the Frei Land Society should not be approved.

REFORMS RECOMMENDED BY FEDERAL AUTHORITIES.

After the conclusion of the important inquiry, upon the motion of the Swiss Frei Land Society the Federal authorities, while deciding to maintain the prerogatives of the Cantons, nevertheless recognized and set forth the need of establishing a certain unity in the laws of the Cantons. The need was expressed for a certain coordination in the matter of regulations still existing in favor of navigation, together with those defining the right of expropriation and prescribing the procedure to be followed. It was recognized that there should be uniformity in the regulations governing the diversion of waters.

It was decided to recommend to the Cantons that they incorporate into their laws regulating the control of waters the following principles:

1. The cancellation of prescriptions relative to navigation, in so far as they interfere with the development of water-power plants, unless said prescriptions are justified by the actual demands of transportation.

2. The adoption of the principle that all progress in the utilization of water power shall be considered as of public utility and that in consequence all installations for power purposes can demand the application in their favor of the laws relating to expropriation.

3. The formation of companies for the economic improvement of watercourses utilized by many manufacturers, with compulsory participation of all interests.

4. The right of the cantonal authorities to investigate the industrial value of proposed enterprises and to base their decisions relative to application for power sites on the results thereof; also, their right to reserve to their own use or that of an interested community any power site; in case of such reservation, the period which it shall cover and the form of notice that shall be given by the Canton or community of which it is in favor.

5. The reservation that, in case of damages sustained by the owners of water-power plants by reason of improvements made in watercourses in the public interest, said owners shall not be entitled to indemnity.

6. The limitation of the term of the concession to a fixed number of years, with clauses of forfeiture in cases of nonutilization, or of redemption by the Canton.

7. The establishment of a cantonal register of the water regulations, following uniform standards for the entire Confederation.

With reference to intercantonal relations, the council of state was of the opinion that the Confederation should have the right of intervening in all cases where the operation of a water power involved two or more Cantons, upon application from one of the Cantons or from the applicant for concession. Intercantonal relations must be regulated by federal law. Federal law or regulations must also apply to questions of public security as affected by the constructions and electric conduits of high tension.

Finally, the report of June 4, 1894, is concluded with a proposal relative to the establishment of a complete and exact statistical record of water powers.

It will be seen that in Switzerland respect for the prerogatives of the Cantons and communes has not hindered the nation from endeavoring to exercise its beneficial influence in all legitimate ways.

DIFFICULTIES INVOLVED IN ELECTRIC TRACTION OF RAILROADS.

The federal authorities have acted only by giving advice. Will they never feel the necessity for more effective intervention? A very serious difficulty will, without doubt, spring up. The Swiss Confederation has redeemed all the railroads in general public use, and will take over the direct operation thereof within two years. How will Switzerland solve the problem that has so passionately agitated Italy, and reserve to itself the water powers necessary to the electric traction of its large railroads? There is nothing to indicate the manner in which the problem is to be approached and solved, whether by friendly agreement between the Confederation and the Cantons or by the passage of federal laws. It is clear that, before committing itself, the Federal Government is endeavoring to procure all necessary information. The important statistical work of the Swiss hydrometric service will probably have as its principal purpose the furnishing of precise data on this subject. The Federal Assembly, at its session of December, 1898, took the first step. It invited the Federal Council to present a report on the question of whether the nation should not secure for itself the powers furnished by watercourses of constant flow, favorably situated for use in the development of the railroads of the nation.

In what way has each of the Swiss Cantons, since the inquiry of 1891, modified its standards and laws, either to accommodate them to the new demands of hydro-electric industries or in consideration of the advice of federal authorities? We are not yet completely informed in the matter, our investigations so far having covered only a small number of Cantons. It appears that there is a very marked tendency to imitate the example of Geneva, which is very encouraging. Everywhere the Cantons and communes are studying the matter of developing and exploiting to their advantage the vast enterprises of power distribution. We will cite the Canton of Vaud, which is trying to bring to Lausanne power from the upper Rhone; that of Fribourg, which has decided to create a distribution system to be served by the powers of Montbovon and Hauterive; that of Zurich, which, after having settled, through the federal tribunal, its difficulty with Schaffhausen relative to the utilization of the Rhine, proposed to establish on that river four plants of 25,000 horsepower, from which it will distribute power within all the centers of commerce and industry.

In this connection it may be said that, by reason of their administrative precedents, the Swiss people have been accustomed for a long time to the idea of their Cantons and communes embarking in industrial enterprises, as is indicated by the form adopted for their encouragement of public-utility enterprises. The Canton of Berne, for example, has aided its railroads by taking their stock, and the grand council announced to the people of Berne in a message of January 28, 1897, that the nation had recovered, without any loss, the fifty millions that it had invested in the construction of the first railroad system, and that it proposed to cooperate in like manner in the establishment of the second system by taking stock to the extent of 40 per cent and for some lines even 60 per cent of the capital required in first construction. From the results first obtained, it is hoped that the hydro-electric enterprises for distribution of power may prove even more advantageous to cantonal and municipal financial investments than have the railroad enterprises.

WATER-POWER CONCESSIONS IN CANTON OF BERNE.

In the Canton of Berne a large number of concessions for water-power developments have been granted to groups of communities, as for example, the company at Hagneck, composed of the towns of Nidau, Tauffelen-Geriafingen, Hagneck, Bienne, Cerlier, and Neuveville; and that at Wangen, composed of the towns of Wangen, Wiedlisbach, Walliswil-Wangen, Walliswil-Bipp, Berken, Bannwil, and Graben. Many more might be cited. But, in the absence of municipal activity, private initiative has also taken part in the development of water powers. The following quotation indicates the attitude of the executive council in the matter:

> We consider that it is the communes on which the law imposes the obligation of establishment and maintaining dikes and dams, and who for years and for centuries have had to bear the expense of maintaining the banks and protection works, without taking into consideration the great damage to which they are often subject on account of inundations, who should profit by the wealth that lies in the utilization of water powers. They have the first right to obtain concessions, and the undersigned [M. Dinkelmann, director of public works, October, 1891] misses no opportunity to call the attention of the representatives of the community authorities to this fact. All demands for concessions must be published and the specifications filed in the proper communes. The authorities of the commune can oppose them and can intervene as applicant and thus secure by cheap water power the means of sustaining and improving their industries. *It is thus our purpose to have the country itself profit by the water powers located.*
>
> If, for any reason, the commune can not or does not wish to take the matter into its own hands, it seems to us that it will be the duty of the nation to see that the country is not completely deprived of its water powers and to arrange that the commune can have, at net cost, the use of at least enough water power for public-utility works, electric lighting, distribution of water, etc. We recommend the regular insertion of such a condition in concessions of this class.

This definition of position is an extract from a voluminous report, ratified by the executive council and by the grand council of the Canton of Berne, having for its object the examination of concessions for water powers, following the federal inquiry brought about by the petition of the Frei Land Society.

The report demonstrates first and foremost that the right conferred by the law of Berne "in the matter of the utilization of watercourses presents many deficiencies and is very defective," and that until a new law is promulgated it will be necessary to seek improvement in the limits of existing legislation. Finally, it proposes a formula for concessions which seems to have the proper precautions and clearness. This formula will be followed until the situation is a little clearer and until there shall be formulated, with the cooperation of jurists and technical experts, a comprehensive law.

The formula in question provides certain rules in the matter of filing of application, examination and approval of projects, assignments, and modifications, concerning which no comment need be made. It also includes, however, two articles which it will be well to cite in full:

ART. 13. If future laws shall confer upon the nation a monopoly of the utilization of water powers or of their transmission by electricity, compressed air, etc., or if the nation or the communes shall find need, in connection with their public services, for water powers that have been conceded, any existing authorization may be withdrawn without indemnity in case the articles of concession do not formally guarantee indemnity; likewise, except in such case as above mentioned, the concessionnaire has no right to indemnity when changes made in watercourses in the public interest no longer permit him to use the water for his power plant.

ART. 14. If future laws shall limit the term of concessions of this class or shall exact specific rentals for the utilization of water powers, such new requirements shall also be declared applicable to concessions now existing.

With these two clauses inserted in all articles of concession, the cantonal authorities of Berne may look forward with tranquility to a revision of existing laws. Upon reflection, it will be seen that these clauses are not so drastic as they would at first appear. The laws that shall be promulgated, even the taxes that shall be imposed (the report of M. Dinkelmann refers to taxes), could not be too severe in effect so long as they permit the development of powers not theretofore utilized. In retrospectively applying these laws and taxes to enterprises already developed, one may be certain that such enterprises will not be crushed, for, in the first place, they will have passed through the first years of development, and, in the second place, the waterfalls first developed are naturally the most economical. Concessionnaires who accept such regulations in advance of their promulgation are not, in reality, imprudent. They will even have certain advantages over their future competitors, because generally

they will be in better position to bear the obligations imposed by the communes.

The formula drawn up and approved in 1891 has been applied in the Canton of Berne to numerous commune or private concessions. We will cite especially the concession of power on the Kander at Spiez (Thun Lake). That concession is of 2,500 horsepower; the head is 64 meters (210 feet); the flow about 4 cubic meters (142 cubic feet); the pipes can carry a maximum flow of 8 cubic meters (284 cubic feet). The power will be developed by the Motor Company of Baden and will be used especially on the railroad now under construction from Thun to Bugdorf. The concession act, approved May 6, 1894, includes articles 13 and 14 quoted and discussed above. It contains in addition clauses of forfeiture in case of nonexecution of the projects or of nonutilization of the water, and a reservation in favor of the towns of Wimmis and Spiez of a right to the use of 200 horsepower and 300 horsepower, respectively, at the turbine shaft, at charges equivalent to net cost. This right fails if advantage is not taken of it within a period of five years.

FLEXIBILITY OF CANTONAL LAWS.

We can not review with the same detail all modifications in regulations adopted by the other Cantons following the inquiry of 1891, although it would be a very interesting study on account of the great variety in the procedures adopted. The most striking point is the eagerness of the cantonal authorities, as soon as the necessity was made apparent to them and without waiting for the laborious revision of general laws, to adopt special laws or simply regulative measures for safeguarding in an effective way the public interests involved. Objections in principle or even obstacles presented by antiquated laws do not carry much weight in the face of the accomplishment of a practical purpose.

The flexibility of Swiss law is truly astounding. A few months sometimes suffices to procure a special law necessary to a large enterprise of an exceptional type. A system which permits such rapid organization merits admiration. We will cite the Water Power Company of Avancon, in the Canton of Vaud, which was created, organized, and directed by Professor Palaz, of Lausanne, an eminent specialist on the subject. In March, 1897, Mr. Palaz called a meeting of capitalists for the purpose of explaining to them the object of the enterprise. It involved the development of 1,300 to 3,000 horsepower over a 544-foot fall, to be used principally for electric traction on a system of railroads between Bex, Gryon, and Villars, a system built and operated by the company itself, and secondarily for the

distribution of power to Bex and vicinity. In April, 1897, he had secured the necessary capital, $2,362,000 (1,270,000,000 francs.) The work was commenced in May, 1897; the distribution of power began in January, 1898; the first section of railroad was opened a few months later. Moreover, it should be noted that expropriations were involved. How enviable are administrative procedures that, in the face of incomplete and contradictory general legislation, permit such results.

VARIATION IN LEGISLATIVE TENDENCIES OF THE CANTONS.

A general comparison of the Swiss Cantons with reference to legislation in the matter of water power would be very interesting. Some of them wish to nationalize or municipalize their water powers, while others wish to reserve them to private initiative. It would be very instructive, when the essential elements of such a comparison are available, to ascertain the real causes for the opposing tendencies, which depend, without doubt, on economic conditions and not on artificial or superficial currents of opinion. It would very probably be found that among the partisans of nationalization were the richest Cantons, the most populous ones, the greatest industrial centers, those where the most important field for utilization of water power lies in already existing enterprises. The development of power under such conditions presents little industrial risk. On the contrary, the poor Cantons, where industry is little developed and where water powers do not find such ready application, without doubt recognize the necessity for encouraging private initiative, which alone can create and encourage the locating of the necessary industries under the incentive of great promise of benefits. In this category belong most of the Departments and communes of the French Alps, which can not even hope to follow the example of the rich Swiss Cantons in the direct development of their water powers. But this is not sufficient reason to prevent their assuming an important part in the work of controlling their watercourses by means of retrocessions to industries.

SUPPLEMENTARY NOTE.

By M. O. Leighton.

Since the foregoing statements were written by M. Tavernier, his predictions relative to the necessity for federal intervention in Switzerland have been justified. The congress has completely reversed the action taken in 1894 in response to the petition of the Frei Land Society, and this reversal was approved by an overwhelming vote of the people. The following amendment was adopted on

October 25, 1908, by a popular vote of 292,997, against 52,180 in opposition:

ARTICLE 24b. The Federal Congress shall have supervision over the development of water powers.

The Federal Congress shall make provision for the disposition of water-right concessions, shall prescribe the terms thereof, and shall regulate the transmission and distribution of electrical energy so far as may be necessary to protect public interests and to provide for the proper development of such resources.

All water rights to which the terms of the federal law do not extend shall be under the jurisdiction of the Cantons, which shall dispose of the concessions, regulate the same, and impose taxes and fees for their use, but such regulations, taxes, and fees shall not be so severe as to prevent or inhibit the development of water powers.

The National Government shall regulate and dispose of concessions for powers located on intercantonal and national boundary streams, and shall determine the taxes and fees to be imposed thereon, after hearings have been granted to the Cantons interested, but such taxes and fees shall be collected by the Cantons.

No power developed on a stream located within the Union shall be transmitted to a foreign country without the consent of the Federal Council.

The provisions of the federal law shall apply to water-right concessions already existing, except in cases specifically exempted therefrom by law.

PROPOSED LAW FOR THE REGULATION OF PUBLIC WATER-POWER PLANTS.[a]

GENERAL DISCUSSION.

In order to understand the difficulties presented in the utilization of water power [in France] under existing law, it is necessary to distinguish between navigable and nonnavigable watercourses.

On navigable watercourses that are a part of the public domain the owners of the banks have no rights whatever. The nation can grant permits where it believes wise, without respect to any right of usage. The legislation therefore places no obstacle in the way of development of large water powers on these streams, for the general good. The principal difficulty is that these permits, like all others granted over the public domain, are precarious and can be revoked without indemnity. Consequently it is difficult to induce capitalists to engage in so costly an enterprise.

On nonnavigable watercourses the situation is entirely different. The water is not domain; it is res nullius, and the riparian owners, who are also owners of the stream bed, have a right of usage in the water. They are permitted to utilize the fall provided they do not infringe upon the rights of other riparian owners, and are restricted only by the administrative permit which covers police control. The

[a] Presented in the name of M. Émile Loubet, President of the French Republic, by M. Pierre Baudin, minister of public works, and M. Jean Dupuy, minister of agriculture, to the commission on distribution of power. (Extract from Bulletin of the Society for legislative studies, on the utilization of water powers.)

riparian owner can dispose of his water right, in which the nonriparian owner has no interest. Nevertheless, the rights of the riparian owner apply to the limits of his own property only, for he has to respect the rights of his neighbors across and up stream. If in any development he has used the falls in the stream above the border of his own holdings, and the upstream owners subsequently wish to make use of their rights, they may obtain from the courts a ruling that will deprive him of a part of the power that he has been using. Therefore it is necessary for those who wish to develop large power plants to enter into an agreement with all the other riparian owners who possess concurrent rights. Even the validity of such agreements is contested, it being conceded only with reluctance that rights in the water can be disposed of without reference to rights in the land.

This condition explains the appearance of water-power site speculators, called "pisteurs" or "barreurs de chutes," who by purchasing a narrow strip of shore line acquire riparian rights sufficient to prevent the establishment of power plants, in order to aid them in an effort to sell such rights at an extortionate price. The water powers of such streams are therefore either in the hands of speculators or of small owners who can not possibly utilize them in the manner required by the great industries. To the great detriment of public interests, the powers are thereby rendered unavailable.

There is, however, one case in which it is possible under present legislation to utilize the powers of nonnavigable streams despite all riparian rights—that is, in the case of public works declared of public utility in the interest of the public service. If, for example, a water supply for a town is to be established, or electric power for lighting a city or for use of a street railway is to be installed, a decree will be issued declaring those works of public utility and conferring on the concessionnaire the right to the necessary power, under the limitations and conditions of the decree, independently of all rights emanating from the civil code.

The effect of such a decree is to combine the rights of the individual users into a common right to indemnity for any damages caused by the execution of public works, there existing, however, no right to indemnity except in case of damage actually sustained. A riparian owner who has previously made no use of his riparian rights can not set up a claim for indemnity. Moreover, there is vested in the concessionnaire, as a result of the declaration of public utility, the right of securing, through the process of expropriation, the lands necessary to the execution of the works. This procedure thus permits the utilization of a part of the watercourse in a satisfactory manner whenever the public service is properly concerned, which alone can be the purpose of a declaration of public utility. This principle can

not be applied in the interest of one or of many great industries, nor in the interest of public service and industry combined.

To remedy the defects of the present legislation, two means come naturally to mind, both involving the right of concession of the water-power sites of watercourses. The first means is that adopted by the Parliamentary commission charged with the examination of the law proposed by M. Jouart, reported by M. Guillain. It consists of creating a new right by declaring the power plants as of public utility in all cases where the interest of public service can be claimed, under conditions actually demonstrated in evidence. It involves practically a concession of ownership in water power destined for private industries, under the obligation to reserve water or power for eventual public service. This would be, in effect, a right of perpetual proprietorship in the water power and the works necessary to the establishment and operation thereof, constituting a "conceded power plant," rather than a "power plant of public utility." Such a concession would be very similar to concessions for mines. To follow the same line of thought, this new private right might be made not a right of perpetual proprietorship but a right of temporary usage, which after a certain period would revert to the nation.

The second means consists of adopting as a basis for the reform the concession in regard to public service just as it exists to-day; that is, the concession for public works. It would be sufficient to extend this to all cases by applying it to private privileges now existing or to be created in the future. This is the system adopted in the proposed law; it is justified by the following considerations:

1. It is preferable not to attack any of the general rules of the civil code or the special principles of legislation regarding waters. The establishment of a new water right might involve serious difficulties, theoretical as well as practical. It will be better to adhere to a legal principle already established, defined, and practiced, viz, the concession for public works with amendments necessary to cover the above-mentioned needs.

2. It will be futile to have two different types of concession, one for industrial purposes and the other for public works. Standards for such will be difficult to establish, for in all cases there will be a possible or prospective public interest as well as a private interest to be served at the same time. For the highest utilization of the power this must always be so. Sometimes the public power plant must turn over its surplus to the private industry; sometimes the industrial plant must help out the public service. On the other hand, the admission that a proposed enterprise is of sufficient general utility to merit the use of the declaration of public utility, regardless of the rights of others, places an immediate obligation on the nation to reserve unto itself the right to impose on the concessionnaire the obligation to develop a large water power, destined ultimately for

public service, whenever needed. Is it therefore not right to hold that the power plant created under such conditions has the character of a public power plant, permitting the application to it of the system of concessions for public works?

3. This conception has the advantage of taking into consideration the duration of the concession, for it must of necessity, like all other concessions for public works, be limited. A perpetual concession of ownership would present grave difficulties in a case where the development was still in the trial stage, where it would be hazardous to make definite plans for the future, and where the value of the water power might, under certain economic conditions, be increased in proportions impossible to foresee.

4. This plan permits the application of principles that have already the sanction of administrative practice and of the law.

The proposed law, whose general principles will now be set forth, has been prepared in pursuance of these ideas, advantage having been taken of all the provisions of the project of the parliamentary commission that can be adapted to the system of concession.

DISTINCTION BETWEEN PRIVATE AND PUBLIC PLANTS.

Private power plants are those which will continue to be established under the system of the granting of a simple permit in accordance with the civil code and with present water laws and regulations.

Public power plants are those which are established under the authority of the new law; that is, by means of concession in virtue of an act declaring them of public utility. Such a declaration shall be made by a decree rendered in accordance with the decision of the state council, save in exceptional cases, for which a special law is necessary.

Power plants on ordinary streams, with a gross capacity of 100 horsepower or more, must always be established as public plants. In such cases there is always a possibility of the exploitation of a large power, which overweighs the ordinary considerations in connection with a private plant under present conditions and which justifies the intervention of the Government, so that there may be assured a reservation of power sufficient for the future needs of public service. It is intended that this shall not affect private powers which exist at the time of the creation of the law, except those plants whose capacity the owners propose to increase.

UNIFORMITY IN REGULATIONS FOR NAVIGABLE AND NONNAVIGABLE STREAMS.

Legislation with reference to public power plants shall apply to navigable as well as to nonnavigable watercourses. The result of such a provision will be to avoid the uncertainty that has existed with reference to public power plants on navigable watercourses. This

provision is absolutely necessary to encourage the establishment of large industries, which can not with financial safety risk possible arbitrary action of the administration, which is free at any time, under present conditions, to revoke the permit without indemnity or to undertake in the interests of navigation works that might bring disaster to the investment. No inconvenience will result from putting an end to the arbitrary control, which is much more damaging to the highest development of natural resources than it is profitable to the interests of the public works. Public water-power plants should have the same guaranties over all watercourses as those established under title prior to the year 1556 or before the national sales under the Revolution. It has been recognized in various instances that the public domain does not prevent the nation from conferring on concessionnaires, by means of the declaration of public utility, certain rights the withdrawal or diminution of which gives rise to indemnity. This principle applies to concessions for street railways over public roads. What it is possible to do on public-land domain it is possible to do on public-water domain.

CHARACTER OF CONCESSION.

1. The concession is granted by the nation in the interest of industry and of the public service. It can be granted either in anticipation of an immediate public service, with the privilege of recovery either at that time or in the near future; or for the use of one or more private establishments, with reservation of quantities of water and power sufficient to supply the public service ultimately to be created.

2. The concession covers water power and works, lands, and structures appurtenant to the operation thereof, as well as canals designed for purposes of drainage or irrigation, which may be imposed upon the concessions, but does not extend to the plants or equipment which are erected for the industrial utilization of the power created and which are located at a distance from the site. The separation is complete between the public water-power plant and the transmission system for private or public utilization.

3. The concessionnaire may dispose, as he sees fit, of water or of power not immediately appropriated to or reserved for future public service. On the other hand, he is bound to furnish to present or future public service water and power under conditions and at rates fixed by the conditions of the concession. In order to avoid loss of benefit from water and power not now utilized but merely reserved for future public service, the law provides that it may be temporarily appropriated to private industries by specific contract. The conditions of the concession prescribe the circumstances under which such contracts can be made and the period of notice which shall be

given when it becomes necessary to furnish such power for the public service. It might, for example, be advisable to let contracts for a portion of the power for a long period and for other portions for shorter periods, according to the probable proportions of the future needs for the public service.

4. The construction work shall be subject to the approval of the minister only in case public safety or the regulations concerning control of waters are affected, or when the works to be constructed shall involve expropriation. In all other cases administrative authorization is unnecessary.

5. The public power plant, with all its stationary appurtenances, is classed as public domain: its works are considered like those of the public highway, for purposes of protection against infractions of contract.

6. The administration shall have the right to prescribe measures necessary in the interest of public health and safety, as, for instance, the prevention of inundations, and the concessionnaire shall have no right of indemnity. In all other cases, on the contrary, if the measures prescribed or works constructed (as, for example, works constructed in the interest of navigation on navigable streams) result in any difficulty whatsoever in the operation of the plant the concessionnaire shall have a right to indemnity.

METHOD OF GRANTING CONCESSIONS.

The concession shall be granted after the filing of an application setting forth the advantages which the applicants believe will accrue to the public interest, and after examination by a "mixed commission on water-power plants," created for that purpose. It imposes upon the concessionnaire obligations of two kinds—first, the duty of furnishing a certain quantity of water or power for the public services, either free of charge or at an equitable rate; second, financial cooperation, when it shall be necessary, in other public-utility enterprises of the section.

A question may arise as to whether it would be good policy to exact payment of a rental. There is no doubt that the imposition of such a charge would be justifiable. The principle has been approved in connection with present legislation concerning plants on navigable streams. It is desirable, however, to avoid giving to the proposed law an appearance of being a measure for revenue. It is better to obtain from the applicants the equivalent of rental by making provisions that will be in the interest of the public service. This may be accomplished either through a reduction in the rates for furnishing power (it sometimes being possible even to obtain this gratuitously) or through an agreement on the part of the concessionnaire to

perform certain services in part or in entirety, such as the construction of important public works, the benefit from which will accrue to the region in which the concession is located. Such services may include the construction of a roadway, a railroad, a street railway, the laying of conduits for lighting, distribution of power for smaller industries, etc. This would be an extension of a principle recently introduced into concessions for mines, which makes for more profitable cooperation between the industrial interests and those of the general public, a point which should not be overlooked.

RELATIONS WITH THIRD PARTIES — DAMAGES — EASEMENTS— EXPROPRIATIONS.

1. *Usages.*—The works are public works, and damages resulting therefrom may give rise to indemnity, under ordinary conditions, in accordance with regulations now in force under the law of December 29, 1892, and with the distinctions recognized under the decision of the council of state. The declaration of public utility renders void the rights of usage which constitute an obstacle to the right conferred upon the concessionnaire, and converts them into a right for indemnity for damages caused by the execution of the works. Only those who sustain actual damage can claim indemnity, such as those who are deprived of water or of power of which they have made beneficial use. The concessionnaire can always free himself of this obligation of indemnity by restoring, in kind, to the users the water or power so confiscated. This is a method of settling damages which often has the double advantage of being more economical for the concessionnaires and of avoiding the wiping out of power plants or irrigation systems previously existing.

2. *Landowners.*—Damages to landowners may result either from the occupation of their lands in connection with the establishment of works, or from flowage of lands occasioned by dam construction. The proposed law distinguishes between a damage which would put the landowner to little trouble and would entitle him merely to indemnity for granting a right of way and a damage involving expropriation. Rights of way would be granted for the establishment of canals, underground conduits, and power transmission. The conditions controlling the granting thereof are determined by civil tribunals, charged with the duty of reconciling the interests of the enterprise with other proprietary interests. The question was considered of defining in the law the various conditions under which rights of way could be procured, but it appeared that it would be difficult to establish sufficiently clear and fine distinctions to cover all contingencies, and consequently it was believed preferable to leave the matter to the control of the civil tribunals. The occupation of the river bed and

the submergence of shore lands not susceptible of cultivation can be accomplished by paying for the right of way, without the necessity of resorting to the expropriation procedure.

In all other cases—that is, in all cases where occupation by acquiring a right of way is not practicable—the concessionnaire must acquire title to the necessary lands upon which his works will be built or which will be submerged by the raising of the water level. The method of procedure in expropriation is governed by article 16 of the law of May 21, 1836.

TERMINATION OF CONCESSION.

A concession shall be terminated, first, by regular expiration of the term thereof; second, by redemption; third, by forfeiture. The common rules in the matter of concessions for public works must necessarily be applied here. It has, however, seemed advantageous to formulate certain special provisions in order to assure a continuation of the service after the termination of the concession and to avoid the uncertainty and interruptions in the enterprise to which changes in ownership might give rise. When a concession is terminated, the new concessionnaire (and in the case of redemption, the nation) is bound to guarantee for a period of five years the fulfillment of contracts held by the old concessionnaire for the furnishing of water and power, subject to the limitations imposed by the controlling conditions of market at that time, and to assure the granting of preference to such public-service demands as may exist.

It is also important, in case of the regular expiration of the period of concession, to provide that the new concession shall be granted some time in advance of such expiration, so that there may be no period of uncertainty just previous thereto. It seems reasonable, as well, to give to the holding concessionnaire the preference in the matter of new application, if he offers terms as advantageous to the nation as those of any of the new applicants. A change in concessionnaire is not always desirable and has no value other than that of securing readjustment of terms in harmony with scientific progress and industrial development. If such advantageous conditions are secured it is usually better for all interests to have no change in the concessionnaire. To this end the proposed law imposes on the administration the duty of arranging the new concession within the five years preceding the expiration of the old one. The method of procedure is identical with that followed in the first concession, except that the right of preference is accorded to the holding concessionnaire. In order to avoid delays which will prolong the examination up to the final days of the period of the first concession and to avoid falling into the uncertainty that would result therefrom, it is

decreed that, if two years previous to the expiration no new concession is being instituted, the concessionnaire can demand an extension of his concession for a period of ten years. This ten-year period of extension seems necessary, and at the same time sufficient for the amortization of the expenses of repair and improvement that the concessionnaire would feel called upon to make when entering on a new period of operation, and to encourage him in so doing.

These provisions as a whole seem to overcome the greater part of the objections made by partisans of the system of perpetual ownership to the system of temporary concession. Such objections are generally based on the difficulty of assuring a good development during the period of change.

With reference to redemption, the proposed law provides that indemnity shall be fixed by arbitration, under the principles laid down by article 11 of the law of June 11, 1880, concerning railroads of local interest. In order to simplify the procedure, in case of forfeiture or redemption, it is proposed to give cognizance to the state council direct, without requiring review by the council of the prefecture; this provision is in accordance with the law of June 11, 1880, above cited.

The proposed law, which contains four sections and eighteen articles, is submitted below.

THE PROPOSED LAW.

SECTION I.

ARTICLE 1. Hydraulic powers, from whatever waters they may be derived, shall be classified as *private powers* and *public powers*. Private powers shall continue to be governed by the laws and regulations now in force. Public powers shall be regulated by the following provisions:

ARTICLE 2. Public powers are hereby conceded to the nation in the interest of industry and public service. When the only use immediately foreseen is the serving of one or more industrial establishments, the reservations necessary in the interest of eventual public service shall be embodied in the conditions of the articles of concession.

ARTICLE 3. Public powers are declared of public utility and conceded by decree of the state council, based on the report of the minister of agriculture in the case of nonnavigable waters or of the minister of public works in the case of navigable waters, and after inquiry and advice of the general council of the Departments, of the municipal councils of the towns interested, and of the commission created under article 16 hereof. No declaration of public utility shall be made in the absence of legislation authorizing the same, in the case of proposed works involving the diversion of water from

its natural channel for a distance greater than 12 miles (20 kilometers) measured along the river bed. Such legislation shall, previous to passage, have been submitted to the state council. The modifications ultimately applying to the use and distribution of the water power and diverted water are authorized by decree of the state council.

ARTICLE 4. The conditions of the articles of concession shall fix—

1. The period of concession.

2. The works, grounds, buildings, and equipment of all kinds that constitute the stationary appurtenances of the concession. Such appurtenances comprise installations for the improvement of the regimen of the stream, the diversion and retention of water, the conversion of hydraulic power into mechanical or electric energy, the transmission of water and power, and finally the maintenance and operation of the various installations. They do not comprise works designed for the utilization of the power produced or water furnished, which might exist irrespective of the concession.

3. The amount of water diverted by the plant, and especially the minimum volume of water to be retained in the natural channel, or to be reserved in the interest of municipal water supply or of irrigation.

4. General conditions concerning the location of reservoirs and dams, the establishment of canals for diversion, discharge, waste, etc., and the character of the works which the concessionnaire is bound to establish without regard to the obligations to the public which he thereby incurs.

5. Charges imposed on the concessionnaire, whether in the form of water or power to be furnished to the nation, to the Departments, to towns, or to properly authorized companies, or in the form of financial cooperation in public-utility enterprises in the region.

ARTICLE 5. The declaration of public utility has the effect of classifying as a part of the public domain water-power plants and their stationary appurtenances defined in the articles of concession in conformity with paragraph 2 of article 4 hereof. Such works are considered as like those under the jurisdiction of the commission of public ways, especially in connection with the suppression of violations. Such violations are liable to a penalty ranging from $3 to about $55 (16 to 300 francs).

ARTICLE 6. Plans for construction of works which affect public safety, or the control of waters, and the general provisions of those involving expropriation are subject to approval by the competent minister. Construction of other works is not subject to administrative regulation.

ARTICLE 7. The concessionnaire maintains the right to dispose freely of water and power not appropriated to or reserved for public

service. Power so reserved and not demanded for immediate use may, pending such demand, be sold to private parties, under specific agreement, the terms of which shall be fixed in the articles of concession.

ARTICLE 8. Except in cases involving public health and safety, the concessionnaire of a public power, even when the power is situated on a navigable stream, has a right to indemnity for injury due to works constructed or measures prescribed by the administration.

SECTION II.

Rights and obligations of the concessionnaire with respect to the public.

ARTICLE 9. Works constructed by the concessionnaire in the establishment of a public power plant are public works. The declaration of public utility confers upon anyone deprived of water of which he has previously made use the right of indemnity. Reparation may consist entirely or in part of compensation in kind.

ARTICLE 10. In consideration of the payment of equitable and necessary preliminary indemnities, the concessionnaire may—

1. Establish and maintain, on or beneath private property, canals, tunnels, and underground conduits necessary to the operation of the power plant or to the fulfillment of the obligations imposed by the decree of concession in the interest of irrigation or drainage, provided that such works do not involve serious difficulty in the use of the surface of the ground by said private parties.

2. Conduct power-transmission systems over or under the ground, for which purpose he may erect the necessary supports and install accessory apparatus for the proper operation of such transmission systems.

3. Occupy the river bed and by raising the water level submerge the uncultivable shores of nonnavigable watercourses.

Existing buildings, yards, gardens, parks, and inclosures connected with residences can not be subjected to the rights of way established by this article.

In the matter of application for such rights of way, the courts must reconcile the interests of the enterprise with property interests. They may authorize a provisional execution of the works in consideration of a deposit by the concessionnaire of a sum fixed by them.

ARTICLE 11. In all cases other than those in which the rights of way defined in the preceding paragraph can be established, the concessionnaire is bound to acquire all lands necessary for the establishment of all works constituting the plant and its stationary appurtenances, as well as for proper construction and maintenance of dams.

Indemnities shall be determined in accordance with paragraph 2 et seq. of the law of May 21, 1836.

SECTION III.

ARTICLE 12. At the expiration of a fixed term the concession, together with all obligations as determined by the conditions of the articles of concession according to article 4 hereof, shall revert to the nation without indemnity. Within five years immediately preceding such expiration steps must be taken toward the institution of a new concession. The holding concessionnaire has the right of preference under equal conditions. If, two years before such expiration, no new concession has been instituted, he shall have the right to demand the extension of his concession for a new period of ten years. The nation or the new concessionnaire continues to be bound for a period of five years after the expiration of the original concession to fulfill the conditions of contracts for furnishing water or power held by the former concessionnaire to the public services, and to individuals after the needs of the public service are satisfied. In no case can the nation be required to furnish larger amounts of water or power than those rendered possible by the conditions of utilization of the concession at the time of its reversion.

ARTICLE 13. The nation may at any time after the expiration of the first fifteen years repurchase the concession. Such redemption is decided by decree in the state council, in the presence of the concessionnaire, and must involve the entire concession. The nation is bound to fulfill the regular contracts for furnishing water and power entered into by the concessionnaire previous to the decision of the minister instigating the redemption proceedings, under conditions set forth in paragraphs 3 and 4 of article 12.

The indemnity for redemption shall be fixed by a commission created by decree and composed of nine members, of whom three shall be designated by the minister of public works, three by the concessionnaire, and three by selection of the six members already provided. If, within one month after the appointment of the representatives of the nation and of the concessionnaire, they shall fail to make unanimous selection of the three remaining members, such appointments shall be made by the chief justice and associate justices of the court of appeals of Paris.

All disputes relative to the redemption are submitted to the council of state for settlement. Appraisal is obligatory, if demanded.

ARTICLE 14. A concession shall be declared forfeited, under conditions as set forth in the articles of concession, by the minister, but the concessionnaire shall have the right to appeal to the council of state, which shall, in case such forfeiture is found to have been un-

warranted, allow indemnity to the concessionnaire. The decision of the minister and the judgment of the council of state are announced to the concessionnaire and published in the commune in which the power plant is situated. The minister may, if he deems desirable, and shall, if requested so to do by the forfeiting concessionnaire or by owners of agricultural or industrial establishments holding valid contracts for the furnishing of water or power, institute proceedings for sale of the concession at public auction. Petition for such auction sale shall be made within three months after the publication of the decision of the minister or of the judgment of the council of state in case of appeal, and the petitioner must guarantee in advance the necessary costs of sale. The forfeiting concessionnaire can not become a purchaser. The proceeds of the sale belong to the concessionnaire. The purchaser is vested with all the rights and obligations of the forfeiting concessionnaire, with respect to both the public and the nation, under the conditions provided in paragraphs 3 and 4 of article 12.

SECTION IV.

General conditions.

ARTICLE 15. In case the concessionnaire shall fail to comply with conditions imposed in the articles of concession, or in ministerial decisions concerning details of construction, or shall disregard any water laws or regulations, or stipulations concerning duties to be fulfilled to the public service, the same shall constitute a violation of law and shall be subject to the same treatment as in matters relating to public ways, punishable by fine of 16 to 300 francs ($3 to $55). In case of repetition of the offense within the same year, the maximum penalty shall be 3,000 francs (about $500). Interference with the exercise of supervision shall constitute a misdemeanor, which shall be subject to fine by the proper corrective tribunal of 16 to 3,000 francs ($3 to $500).

ARTICLE 16. There is hereby created, under the jurisdiction of the minister of public works, a mixed commission on water-power plants, charged with—

1. Examining and compiling data procured by cooperation between local services with reference to the control of waters, with a view to their utilization for the public service, industry, and agriculture.

2. Giving advice upon applications for concessions for water-power plants and upon proposed articles of concession, with a view to the utilization of the water and power for the public service or by properly authorized companies.

This commission shall be composed of (1) one counselor of state, president; (2) five legal advisers, viz, from the department of public works, the director of roads, navigation, and mines and the director

of railroads; from the department of agriculture, the director of agriculture and the director of agricultural hydraulics; from the department of the interior, the director of departmental and communital administration; (3) two members of the general council of bridges and roads and two members of the commission of agricultural hydraulics; (4) two "maîtres des requêtes" (members of the council of state next in rank to counselors); (5) two electrical or railroad engineers; (6) the chief engineer of bridges and roads, secretary.

The members of the commission, other than the legal advisers, shall be named by decree. The legal members, in case of absence or other interference with their duties, shall be represented by one of the members of their department, designated by the competent minister. If all the interested officials do not concur in an opinion of the water-power commission, decision shall be rendered by decree of the council of state.

ARTICLE 17. Public administrative regulations shall determine all necessary measures for the execution of this law, and especially the forms in which applications for concession shall be presented and examined, the arrangement of meetings of interested local services for their consideration, and rules concerning the operation of the commission provided in article 16.

ARTICLE 18. All laws and regulations contrary to this law are hereby repealed.

CHAPTER IV.

LAWS PROPOSED IN THE FRENCH PARLIAMENT.

LAW PROPOSED BY M. ALBERT LEBRUN, FOR REGULATING HYDRAULIC PLANTS ON NONNAVIGABLE WATERCOURSES.[a]

LEGISLATION NOW IN FORCE.

All water-power legislation in France rests on the distinction established by the civil code and confirmed by a century of jurisprudence—that is, on the distinction between navigable waters, which belong to the public domain (article 538 of the civil code),[b] and nonnavigable waters, none of which are included in the public domain.

Of the navigable watercourses the nation has entire disposition. It grants under rental permission to take water, to occupy lands with a view to irrigation, or to erect hydraulic plants; but these permits are of precarious tenure and revocable without indemnity, a feature that sometimes constitutes an obstacle to the utilization of the water, so that a modification of the law is therefore desirable. Such a modification is even now under consideration by the commission on public works.

If a project has the character of a public utility, it may profit by the government concession. Thus was organized, under the special law of July 9, 1902, the Society for Motive Power of the Rhone, which, by utilizing the waters of the river, supplies light and power to a group of Lyonnaise communities.

Nonnavigable waters are governed under articles 644 and 645 of the civil code, which read as follows:

ARTICLE 644. Anyone whose property borders on a watercourse, other than that declared part of the public domain by article 538, may use the water in passage for irrigating his property. Anyone whose property is traversed by this watercourse may also use it as it passes through his land, provided he returns it to its regular channel on issuance from his property.

[a] Report of commission appointed to examine a proposed law regulating water powers on nonnavigable watercourses, Chamber of Deputies, 9th legislature, session of 1908.

[b] Highways, roads, and streets under the control of the State and navigable rivers and streams are considered part of the public domain.

ARTICLE 645. If a contest arises between proprietors to whom these waters may be useful, the courts, in giving judgment, must reconcile the interests of agriculture with the property rights; and in all cases the individual and local regulations concerning the course and usage of the waters must be observed.

The law of April 8, 1898, sanctioned in article 3 a usage which was long discussed, but which was established long ago by jurisprudence:

ARTICLE 3. The bed of nonnavigable watercourses belongs to the proprietor of the two banks. If the two banks are owned by different proprietors, each one of them owns one-half of the bed, following an imaginary line traced down the middle of the watercourse, save and excepting contrary title or limitation.

It is plain from the above provisions that the owner of the bed of the river has the right to use the running water which traverses or borders his property. The nature and extent of this right have long been under discussion, although they have been established by law. It is admitted that "the proprietor of only one bank may use the water as well as he whose grounds are traversed by the stream, not only for irrigation but for industrial purposes, provided always that he does not divert more water than he could use for irrigation." (Statement of grounds of complaint.)

This right of usage is justified by the risks to property arising from proximity to a watercourse subject to rise and overflow and also by the obligations entailed. Maintaining clear channels is one of the obligations of the riparian owner, and in case of nonperformance by the parties responsible the work is done officially under the direction of the hydraulic service and the costs, charged to the fund for departmental cooperation, are then recovered from the recalcitrant proprietors. The expense of cleaning varies from year to year, ranging between a million and a half and two million francs.

Riparian rights being thus defined, what is the method of procedure for regulating hydraulic power on a nonnavigable watercourse?

The riparian proprietor who possesses the full rights to a fall of water, whether owned by original right or acquired by amicable purchase, requests a permit from the administration. For a long time this permit was granted by virtue of the law of August 12–20, 1790, the government decree of 19 Ventose, year VI, and in conformity with the circulars of October 23, 1851, and December 26, 1884. Today the law of April 8, 1898, defines the matter in articles 11 et seq.

ARTICLE 11. No dam or other work destined for the establishment of a canal regulator, mill, or factory can be constructed on a nonnavigable watercourse without the authorization of the Government.

A decree dated August 1, 1905, determines the details of the application of the law.

But this authorization is not of the same nature as the concession or permit granted for a stream forming part of the public domain.

It can not be granted except for reasons of public interest and is more in the nature of a police measure. For example, the Government ascertains whether the flow of the water, the security of the riparian inhabitants, and the public health will not be injured by the projected enterprise. It does not inquire, however, what use the petitioner proposes to make of the water or whether such or such a riparian dweller will be injured by the work in question.

For this reason this authorization is given subject to the rights of the third party; and the courts have the power to appraise the damages that might result. This power of decision may go so far as to demolish works which are considered too injurious to the interests of a riparian inhabitant.

In addition, the Government can withdraw an authorization previously given for these same police considerations, as is indicated in article 14 of the law of April 8, 1898:

Permits may be revoked or modified without indemnity, either for considerations of public health or to prevent or check inundations, or finally, in cases of general regulation, as provided in article 9. In all other cases they can be revoked or modified only on condition of indemnity.

In the interests of agriculture, the laws of April 29, 1845, and July 11, 1847, created an aqueduct and dam service for irrigation in the following terms:

Law of April 29, 1845.—ARTICLE 1. Any proprietor who wishes to use for the irrigation of his property the natural or artificial waters over which he has the right of disposal may obtain passage of these waters over the intervening property by payment of a just indemnity in advance. Houses, courts, gardens, and inclosures pertaining to dwellings are not included in this provision.

Law of July 11, 1847.—ARTICLE 1. Any proprietor who wishes to use for the irrigation of his property natural or artificial waters over which he has the right of disposal may obtain the right to place on the property of the owner of the opposite bank such constructions as are necessary for the collection of the water by payment of a just indemnity in advance. Buildings, courts, and gardens pertaining to dwellings are not included in this provision.

It is proposed to extend the benefit of these provisions to industry, as the latter is not less important to the general welfare than agriculture.

REVIEW OF PROPOSED LEGISLATION FOR PRIVATE POWER PLANTS.

There are two points on which all these measures agree; one is the giving to public plants the right to sell their surplus power to private industry; the other is the extension of the privileges conferred on irrigation enterprises by the laws of 1845 and 1847 to reservoirs and dams constructed for industrial purposes. But if there is agreement on a few points, there is wide divergence on some fundamental questions. The measures relate to two diametrically opposed principles, and

from 1898 to 1904 caused long and heated discussions between their authors, in which all concerned in the utilization of "white coal" were vitally interested.

The first bill is by M. Jouart, deputy, and bears date of March 3, 1898. On July 6, 1900, it was followed by a bill brought in by Messrs. Baudin and Jean Dupuy. Both provide for the direct intervention of the nation in the creation of waterfalls—at least of those exceeding 100 horsepower—by means of concessions analogous to the concessions for public works. The Baudin-Dupuy measure proposes that such concessions shall be limited as to term and be subject to redemption after a certain period; further, that they shall be subject to forfeiture in case of failure to comply with any of the prescribed conditions. The bill further provides that on the termination of a concession the property and appurtenant improvements shall revert to the nation unless the concession shall be extended by agreement, in which case the former concessionnaire has the right of preference over eventual competitors. No right of indemnity is granted to riparian owners who are deprived of water rights and privileges that they have not utilized.

This bill has been widely criticised; first, by riparian owners, who claim that the rights assured to them under article 644 of the civil code have been ignored; second, by industrial concerns which are antagonistic to the nation's interference in purely private enterprises; and, third, by those who, although not directly interested in the hydraulic industry, oppose the abandonment of the ancient legal principle that distinguishes waters of the public domain from those of private possessions.

* * * * * * *

Answering this criticism, other proposals were made providing for the least possible intervention of the nation and the maintenance, with slight modifications, of previous legislation. In this class may be mentioned especially the so-called "congress of Grenoble bill," drawn up by M. Michoud, in which the several riparian dwellers, having rights over the same fall, are treated as coproprietors of a property and are permitted to divide up their interests by a system of legal licitation, allowed under article 815 of the civil code. This licitation takes place in the civil courts, and the sum paid by the purchaser is distributed among the proprietors on a pro rata basis. The purchaser may then with entire security request administrative authorization under the law of 1898. Under a somewhat similar system, supported by Messrs. Hauriou and Ader, liquidation of riparian rights is accomplished by a kind of licitation which is of an administrative rather than a judicial character, as appeal is made to the laws of 1865 and 1888 relating to the constitution of corporate associations. In this the majority of the riparian owners constrain the minority

to agree to pooling their rights in order to create a waterfall, and to acquiesce in the sale. The remuneration is then equitably distributed, as in the case cited above. These bills tend to extend to the limit the rights of riparian dwellers and to reduce to a minimum the nation's power of intervention.

* * * * * * *

In June, 1903, the minister of agriculture organized a commission to study the measures necessary "to insure a better utilization of the water power of nonnavigable streams." This commission was so constituted that all interests were represented. It included members of the council of state, civil and government engineers, lawyers, manufacturers, etc. The conclusions of the commission formed the basis of the bill laid before the Chamber January 15, 1904, by M. Mougeot, then minister of agriculture.

This bill and others of the same kind were studied and discussed until, in 1907, the present commission submitted the following bill, which in the judgment of its members incorporates the best features of its predecessors:

THE PROPOSED LAW.

SECTION I.

Private hydraulic plants.

ARTICLE 1. Private hydraulic plants on nonnavigable watercourses are divided into two classes.

The first class comprises those which are subject only to legislation anterior to the present law.

The second class comprises those which have benefited by the provisions of the present law under the conditions stipulated in articles 2 and 3.

Manufacturers have the choice of remaining under the régime of existing legislation or of asking to benefit by the provisions of the present law.

ARTICLE 2. If a factory desires to benefit under the provisions of the present law, an express request to this effect must be filed, either at the time of the request for authorization of the work, or subsequently if the matter concerns a factory already in existence.

The petitioner must indicate the sections of the banks to be affected by the retention of water by the dams or by the projected deflection of water for use in the factory.

He must prove that he possesses (1) the land necessary for the establishment of the factory; (2) one of the banks required for the site of the projected dam; (3) the riparian rights for at least one-third of the total length of the banks in the section concerned, not

including in the calculation of this third those parts belonging to the public domain of the nation, the Departments, or the communes.

ARTICLE 3. The demand is subject to an examination, whose forms are the same as those of the investigation prescribed by article 12 of the law of April 8, 1898.

It is decided by decree in council of state whether the request shall be granted or denied; it being denied if the conditions necessary to obtain the permit provided for in the law of April 8, 1898, and the present law have not been fulfilled, or if the investigation develops objections that the council of state deems valid.

The permit is barred by limitation if a part of the work, specified in the decree, is not executed within a period of three years after the issuance of the decree. It may always be withdrawn by decree in council of state if the conditions prescribed in the act of authorization, under application of article 6 hereinafter set forth, for the protection of the general public, have not been or cease to be complied with.

ARTICLE 4. When a request for the establishment of a new plant has been filed, competing requests, comprising either in whole or in part the sections of watercourse included in the first request, may be framed under the same conditions as those prescribed for the first. It shall be the duty of these petitioners to notify all preceding petitioners of these requests.

When there are several competing requests for the same fall, preference shall be given to that petitioner who shall prove possession of the largest fraction of riparian rights.

When the requests relating to different sections of the same watercourse are partly competitive, the preference shall be given to the enterprise contemplating the largest production of power, provided the difference in its favor, under average conditions of utilization of the works to be established within a period of three years, as provided in the preceding article, amounts to not less than one-fifth.

When the right of preference can not be determined by either of the preceding regulations, preference shall be determined by priority of demand.

ARTICLE 5. The request for authorization, as provided in the preceding articles, may be filed by a free association of riparian owners, organized under the laws of June 21, 1865, and December 22, 1888. Such association can not be transformed into an authorized association.

The corporation thus organized may cede temporarily or finally its rights over a fall or factory. Its manager has the right to determine for the members the reserves of water in kind, the restitutions of motive power, and the money indemnity, observing always the regulations as set forth in articles 8 et seq. of the present law. He shall distribute among the parties concerned all proceeds resulting from

the cessions mentioned above, save and except when recourse is had to the civil courts.

The statutes determine the procedure in these various operations.

ARTICLE 6. The act of authorization for hydraulic works determines the precautions to be taken for the protection of the general public, especially those concerning the public health, protection from inundation, alimentation of riparian owners, needs of irrigation, conservation and free circulation of fish, and protection of the landscape.

It may contain restrictions relating to the restoration of water in kind at specified points of the section in the interest of enterprises designed to supply nonriparian communities or collective irrigation. These restrictions are null and void if the project to which they relate has not been approved within a period of two years from the date of the act of authorization, or if, after being approved, the work is not executed within a period of three years from the date of the approval.

During the first ten years immediately succeeding the beginning of operation of the factory, any public authority may requisition for the public service it administers a portion of the converted or unconverted power not exceeding one-fourth at low water. This requisition is authorized by a decree setting forth the reasons therefor, rendered in council of state on the report of the minister of agriculture and of the ministers of the departments having jurisdiction over the public services concerned. The requisition is executory only on payment of a preliminary refund of a corresponding quota of the expense of establishment, maintenance, and exploitation of the works or apparatus used for the service making the requisition, or on payment of a corresponding rental fee, if the requisition is temporary.

The Government shall have the power to make requisition, under the same conditions, for a quota of the increase of power at low water produced by works constructed under the terms of the present law, with a view to increasing the capacity of a factory erected before the promulgation of the law.

In case of litigation the sum to be refunded or the rental fee is determined by the civil court on the testimony of experts.

The Government may renounce in whole or in part its right of requisition for a supply of power at a fixed price, agreed upon with the manufacturer. The modifications of the right of requisition and the contracts for the supply at a fixed price shall be approved by a decree in council of state on the report of the minister of agriculture and of the ministers of the departments having jurisdiction over the services concerned.

ARTICLE 7. Permit is given under reserve of the rights of third parties.

The interested parties may lay before the civil court their demands for reserve or restitution of water in kind, for restitution of motive power, or for indemnity.

The judge, in giving sentence, must reconcile the interests of property with those of agriculture and industry.

He may order that a provisional indemnity shall be paid by the manufacturer before operation of the injurious work begins.

He will be guided, however, by the following regulations:

Article 8. For preexistent irrigation or reservoirs of water for domestic supplies the parties interested may demand free restitution of the water in kind. Reciprocally, the manufacturer has the right to discharge this obligation by making this restitution, or by indemnifying, when necessary, each one of the interested parties for the expense entailed on him by the conditions resulting from the utilization of this water.

By exception, and when he has not been notified by the decree of authorization of the express restrictions required by the needs of irrigation, the judge may decree, on payment of indemnity, the diminution or suppression of existing irrigation the maintenance of which would involve excessive difficulties, if the construction of the projected work is clearly of greater importance than the individual enterprises obstructed.

For rights of irrigation and domestic supplies of which no use has been made prior to the request for a permit for the works, the judge will decide whether and in what measure the individual claim for reserve in kind should be allowed, or whether the rights invoked should be satisfied in whole or in part by a money indemnity. The manufacturer may always discharge his obligations to the holders of these rights by furnishing the amount of water in the natural state necessary for their property bordering on the watercourse, under the conditions and at the price they themselves would have had to pay formerly with works using only simple gravity, these conditions and this price to be determined by experts in case of disagreement.

Article 9. The right of riparian owners to the use of water for other purposes than irrigation and household purposes is transformed into right of indemnity.

Nevertheless, if there are preexistent motive powers in the sections of the watercourse affected by the construction of the projected waterfall, the manufacturer must restore to those having rights over such powers, if such exist, all the power of which they have had disposal. This restitution may be made in the form of electric energy, with indemnity for transformation if necessary.

Those having these rights may, if they prefer, give up their right to restitution of the power in kind in exchange for indemnity.

For restitution of power in the form of electric energy, cited above, the manufacturer may secure rights of way for pole lines, etc., as provided in article 12, paragraph 3, of the law of June 15, 1906, conferred on the concessionnaire of an enterprise for distributing electric power which has been declared a public utility.

ARTICLE 10. The factories established under the terms of the present law have the benefit of the aqueduct and dam service as regulated by the laws of April 29, 1845, and July 11, 1847. On payment of a just preliminary indemnity they also have the right to occupy the bed of a watercourse and to submerge the banks by raising the water level.

Nevertheless the owners of the property injured by these services have the right to require the manufacturer to purchase the land submerged as well as the sites necessary for the construction of the works or of surface or underground canals.

The proprietor may compel the manufacturer to construct all the works necessary to insure communication between all the parcels of land traversed.

All disputes arising from application of the terms of this article are under the jurisdiction of the civil court.

SECTION II.

Hydraulic plants declared a public utility.

ARTICLE 11. Hydraulic plants may be established by virtue of a declaration of public utility and may be made the object of a special concession when their principal object is to insure the supply of power necessary for the public services of the nation, the Departments, the communes, and syndicates of communes, or for authorized associations and other public institutions.

ARTICLE 12. The declaration of public utility is made and the concession is approved, after due investigation, by decree in council of state on the report of the minister of agriculture and of the ministers of the departments having jurisdiction over the services concerned.

The declaration of public utility, however, is made by a law passed after investigation by and on the advice of the council of state, when the works relate to the deflection of waters from their natural bed over a line of not less than 20 measured kilometers following the bed.

The concession may be granted, with power of reconveyance, to Departments, communes, and syndicates of communes.

ARTICLE 13. The conditions under which the concession is granted specify (1) the services for which the factory is established and the conditions under which they are to be served; (2) the duration of the concession; (3) the works, lands, buildings, and engines of all kinds which constitute the dependent realty of the concession; (4) the reg-

ulation of the water of the factory, especially measures relating to public health, protection from inundation, domestic supplies of the riparian population, needs of irrigation, conservation and free movements of fish, and protection of the landscape; (5) the rights and obligations of the concessionnaire, both during the time of the concession and at its expiration, and regulations relating to redemption of the concession and forfeiture, if there should be any.

The conditions must be conformable to the type approved by decree in council of state. Every derogation made therein shall be expressly mentioned in the act of concession.

ARTICLE 14. Modifications may be made in the uses of the power, as specified in the statement of conditions, on the demand of the concessionnaire and by virtue of decrees giving the reasons therefor, rendered in council of state after investigation.

In addition, there is at all times liberty to sell and use the surplus power and the residues of exploitation.

Contracts made under the terms of the preceding paragraph will remain valid in case of the return of the factory to the grantor for any cause whatsoever for a period specified in the statement of conditions.

ARTICLE 15. At the expiration of the period determined the concession, with all its dependencies, as specified in the statement of conditions, reverts to the nation without indemnity.

During the ten years preceding the expiration of the concession a new concession may be obtained. Conditions being equal, the concessionnaire in possession has the right of preference.

If, five years before the concession expires, no new concession has been granted, the concessionnaire may demand a prolongation of his concession for another ten years, under the same conditions as the first.

The same provision applies five years before the expiration of each new period of ten years.

ARTICLE 16. Factories declared a public utility have the benefit of the services mentioned in article 10 of the present law. There is also a general benefit resulting from the right-of-way privileges granted by article 9 to private factories subject to requisition for the restitution of power in kind.

The expropriation necessary for the establishment of factories of public utility is effected under the conditions provided for in the last five paragraphs of article 16 of the law of May 21, 1836. If, however, there is question of expropriating lands on which there are buildings, the law of May 3, 1841, alone is applicable.

ARTICLE 17. The decree of concession determines the indemnities which may be allowed, if there are any, for deprivation of the riparian rights held under article 644 of the civil code in all cases in which effective use thereof has not been made.

ARTICLE 18. The factories declared of public utility and their dependent realty, as defined in the statement of conditions, are classed as public domain. Their works are classed in the same category as the works dependent on the commission of public roads, ways, canals, etc., especially as regards punishment of transgressions.

Transgressions are liable to a fine of 16 to 300 francs ($3 to $55).

ARTICLE 19. Factories forming an integral part of enterprises declared a public utility, such as railways, tramways, public lighting and power systems, etc., benefit under the terms of articles 10, 14, and 18, hereinbefore set forth. The other provisions of the present law can be applied to them only by modification of the act of concession, approved under the same forms as the act itself. In default of modification thus approved, they remain subject to the same régime as the rest of the enterprise of which they form a part.

SECTION III.

Collective works for the improvement of the regularity of flow of watercourses.

ARTICLE 20. The execution and maintenance of works designed to improve the regularity of flow of watercourses with a view to industrial and agricultural utilization may give rise to the organization of free corporate associations. These associations may be converted into authorized associations by application of article 8 of the laws of June 21, 1865, and December 22, 1888, provided the conditions of majority, prescribed by the statutes, are fulfilled.

ARTICLE 21. Proprietors of lands and factories who are not members of the association but who would profit directly by the improved regularity of flow of the watercourse can be compelled to pay to the association, when converted into an authorized association, indemnities, which shall be determined by the council of prefecture, save and except on appeal to the council of state.

Actions for indemnities for plus value can be brought only by virtue of a preliminary authorization granted by decree rendered in council of state. The decree may decide that the indemnities shall be payable in annual installments, taking into consideration every year the utilization made of the additional water or motive power resulting from the works.

ARTICLE 22. The proprietors of lands and factories which would profit directly by the improvements in the regularity of flow of watercourses made by the works of the nation, the Departments, the communes, or their concessionnaires and by authorized corporate associations may be compelled to pay indemnities for plus value under the conditions laid down in article 21. Actions for indemnity can be

brought only by virtue of a special authorization, granted, on proposal of the minister of agriculture, by the act which declared the works a public utility.

SECTION IV.

General provisions.

ARTICLE 23. An order of public administration will determine the measures necessary for the execution of the present law. This especially applies to (1) the papers to be sent with the request, as set forth in article 2, and also the procedure to be followed to file the request and to fix the date thereof; (2) the method of verifying the execution of the work within the period prescribed in article 3, and the forms by which this period may be prolonged in case of delay due to obstacles beyond human control; (3) the method of notification and examination of competing requests, the limits of time within which modifications of requests under examination may be considered with a view to determination of preference; (4) the method of verification of the limitations set forth in the second paragraph of article 6; (5) forms of the examination to be made of modifications relating to the uses of the power from factories of public utility under the terms of article 14; (6) forms under which the interested parties shall be admitted to plead their claims to the indemnities provided for in article 17.

LAW PROPOSED BY M. BAUDIN AND M. MILLERAND FOR REGULATION OF HYDRAULIC POWER PLANTS ON WATERCOURSES AND CANALS OF THE PUBLIC DOMAIN.[a]

DIGEST OF THE GOVERNMENT PROPOSAL.

Two kinds of power plants are recognized—(1) private power plants, the energy of which is used exclusively for the industrial needs of one special establishment and affects only private interests; (2) public power plants, which are veritable factories of energy destined to furnish power and light to a whole district and which are therefore of public utility.

The separation of the two kinds of plants is well defined in practice. Unless the public sale of power is intended by those operating power plants, the Government must grant a permit for the use of the water. Under the present rule this permit is precarious, as the plant, according to the interpretation of the law by the state council, can be subjected to restrictions and regulations made in the interests of the public, and the owner can be compelled to render special services

[a] Report of the commission of public works, M. Pierre Baudin, deputy, Chamber of Deputies, Ninth Legislature, extra session of 1908; supplement to the report of the meeting of December 17, 1908.

for the benefit of the public; but if he has received no aid from the Government and has been left to his own resources in the establishment of his plant, he nevertheless remains a free agent. After meeting his obligations in the form of taxes, he need account to no one for the power that he derives under the permit.

As soon, however, as power is offered for sale, the character of the power plant changes completely. It becomes a public utility and its functions must not be hampered by private interests. The grantee is no longer a private user of power for industrial purposes, but in the operation of his plant he is subject to government regulations which may be productive of results not specifically beneficial to his private interests, but which are justified by public policy.

Certain conditions and limitations may be specified in the permit and a special tax may be levied to regulate the conditions under which the service may be used. In other words, exclusively private interests become abolished or become secondary to public interests. A third party, namely, the public, is introduced into the arrangement, with power to appeal to the courts for adjustment of grievances. Finally, there remains to be considered the interest of the concessionnaire, the value of whose property may be decreased and whose profits may be reduced by the application of the regulations prescribed.

CRITICISM AND JUSTIFICATION OF THE NEWLY PROPOSED LAW.

The commission does not object to the legal place assigned to public power plants. It acknowledges that the proposed system by which private power plants shall be governed would, in large degree, do justice to collective interests. But the character of the private plant, as proposed in the bill, in itself justifies certain reservations and criticisms. If the question should be decided entirely on the legal principles involved, the commission would recommend the absolute abolishment of private power plants.

It should not be forgotten that a permit to take power from a river belonging to the public domain involves a concession of public property. The legal phase of the transaction is therefore not influenced either by the amount of power granted nor by its final disposition. Such a concession certainly reduces the amount of possible public benefit that could be derived from a watercourse. The Government must therefore not only provide that the grantee shall not derive an excessive benefit from this concession, but must insure for itself, in return for the concession, certain guaranteed benefits, specified in the articles of concession.[a]

[a] In Switzerland, where private watercourses are an exception, the system of concession is applied to all power plants of the public domain, as the use of public watercourses for the development of energy constitutes a sovereign right of the Government.

The commission recommends the system of concession for all water-power plants located on watercourses belonging to the public domain, without distinction between private and public power plants. To permit the establishment of private plants on such watercourses without concession would involve the abandonment, without compensation, of a very important portion of the public domain. Private plants are far greater in number than public ones and represent in the aggregate an enormous horsepower. The commission believes that the framer of the bill under consideration did not, in his proposal to allow private plants to be established without concession, take into account the inconvenience which the system of simple permits for such plants would produce. The following quotation from the Government's own dissertation will support the view of the commission:

> Whenever the demand for a grant is made (for private plants) the Government must provide that the compliance with such demand does not injure national or public interests, nor prevent or delay the development of public power plants. In all decisions by the Government preference must be given to public interest.

From this declaration it becomes evident that the idea of government control is dominant, and that without provisions for concession on the public domain such control can not be exercised.

The government representatives, in their conference with the commission, have acknowledged the justice of these observations, but they have also pointed out certain difficulties which would result in practice if the law as suggested by this commission were strictly enforced (meaning the concession for all power plants on watercourses of the public domain).

It was mentioned that if the formalities necessary to the establishment of government control were required from small plants, the procedure would be entirely out of proportion to the importance of the establishments. In addition, the Government would be required to exercise control over a multitude of inferior establishments when its attention should be concentrated on the more important questions of the development of private property. It was also pointed out that under a concession covering a certain term, the owner would be entitled to damages if it were found necessary during that term to confiscate or to damage the plant for any purpose of public benefit. The concession could not be terminated before the expiration thereof except by forfeiture and redemption. Under such conditions, would it seem advisable to increase the already large number of small power plants, which are now useless for public service and which will in the future surely prove to be an obstacle and an unnecessary expense to the Government, if for any reason said Government should be com-

pelled to change the regulations on watercourses on which any of these small plants might be located?

The commission acknowledges the necessity for modifying the concession. It has included in the Baudin proposal a distinction between types of power plants, based on the value of the power in the different watercourses of the public domain. It is not proposed to exempt permanently from the requirements of concession all small power plants, but the commission's recommendations affect those whose present and prospective connection with exclusively industrial private interests is beyond dispute. The question of future utilization is more important than that of present consistency of legal procedure. Every contract having for its purpose the sale of power, of whatever amount, must be placed under concession. This rule will therefore be applied to two kinds of hydraulic establishments—first, power-plant concessions based on the amount of power produced, and second, concessions based on the use to be made of the power.

For the large number of small power plants and for some of those of medium size, the permit system is proposed.

Mention should be made of the joint meetings of the commission and the representatives of the power industry, who have approved the new legislation and have made certain suggestions. The commission had already foreseen some of these suggestions and had provided therefor. It should be understood that neither the executive nor the legislative branch of the Government intends to enact any measure that will inhibit the growth of industry. Without framing a general rule which will meet all unexpected difficulties, the administration must fix the duration of the concession according to the importance of the plant and the amount of capital invested. At the expiration of any concession, preference should be given to the former grantee in making a renewal.

THE PROPOSED LAW.

SECTION I.

Classification of power plants.

ARTICLE 1. Hydraulic power plants established on the public domain shall be classified as "authorized power plants" and "power plants under concession."

ARTICLE 2. "Authorized power plants" shall be defined as those which develop a gross energy of not more than 250 horsepower at low water, and which have not for their principal purpose the sale of power. All other power plants shall be designated as "power plants under concession."

SECTION II.

Authorized power plants.

ARTICLE 3. Authorized power plants shall be governed by laws and regulations now in force. All authorizations are subject to cancellation, and they shall not in any case be granted for a period longer than fifty years. At the expiration of that period the grantee shall, if the authorization is not renewed, restore the premises to the condition previously existing or deliver the power plant to the nation without indemnity therefor, as the nation shall elect.

ARTICLE 4. In the case of power plants now in existence, the fifty-year period fixed by the preceding article shall begin from the time of the passage of this act.

ARTICLE 5. The surplus power of any authorized plant may, under exceptional conditions, be sold to the public under regulations promulgated by the minister of public works.

SECTION III.

Power plants under concession.

ARTICLE 6. All concessions for power plants shall be limited to a specified term and shall be made the subject of articles of concession, conforming to one of several types approved by decree of the state council, with modifications and conditions which shall be expressly specified in the articles of concession.

The concession shall be granted in the name of the nation by decree rendered in the form of a public administrative regulation. In case the project necessitates the diversion of water from its natural course for a distance greater than 20 kilometers, measured along the river channel, or if the capacity of the proposed plant is greater than 18,750 horsepower, no concession shall be granted except by enactment of a special law in Parliament.

Subsequent regulations concerning the use and distribution of the hydraulic power shall be promulgated by decree of the state council, after inquiry.

Provided, That the foregoing requirements shall not apply to power plants which constitute a component part of an enterprise declared to be of public utility, which shall be subject to special regulations determined by decree of the state council.

ARTICLE 7. The concessionnaire shall be invested with authority to execute the works defined in the articles of concession, together with all the rights which the laws and regulations confer upon the administration in the matter of public works, and said concessionnaire shall in turn comply with all the obligations imposed upon the administration by such laws and regulations.

In case of expropriation, the procedure must conform to the law of May 3, 1841, in the name of the nation and at the expense of the concessionnaire.

ARTICLE 8. The holder of a concession for a power plant shall have the right to occupy private property necessary for the storage of water and for the establishment of underground conduits supplying water to the power plant and conducting it therefrom, in conformity with the terms of the concession as approved by the administration.

Such occupation of private property must be preceded by notification to all parties interested and by special inquiry held in each of the communes where the aforesaid works are to be established.

Indemnities accruing from such occupation shall be regulated in the first instance by the civil tribunal; if appraisal is necessary, the tribunal shall name but one appraiser.

ARTICLE 9. The articles of concession for power plants shall specify—

1. The location of the plant.

2. The duration of the concession.

3. The works, lands, housing, and equipment of every kind constituting the stationary appurtenances of the concession.

4. The amount of water to be used by the power plant, and particularly provisions for its regulation so as to avoid damage to navigation and to afford protection against floods, to safeguard the public health, to conserve the interests of the people in the matter of water supplies and irrigation, to protect and provide for the migration of fish, and to preserve the natural beauties of the landscape.

5. The amount of rental to be paid to the nation for the use of the water and the obligations incurred in connection with works previously established by the nation for purposes of navigation, if any, together with all other financial conditions imposed by the concession.

6. The amount of sureties.

7. The maximum charges for the sale of power to the public.

8. The amount of water or power to be reserved for the benefit of public services and the conditions under which it must be placed at public disposal.

9. The methods of national control and provisions for the expense thereof.

10. Conditions under which the right of redemption may be exercised by the Government.

11. The rights and duties of the concessionnaire, in general, both during the concession period and at its expiration.

ARTICLE 10. All the improvements comprised in the power plant, including the real property and rights of way occupied by it, as

specified in the articles of concession, shall become a part of the public domain and shall be subject to police regulations in the same manner as are the public roads, for violations of which there shall be imposed penalties of 16 to 300 francs (about $3 to $55).

ARTICLE 11. At the expiration of any concession for a power plant the nation shall immediately take possession of the plant and appurtenances constituting a part of the public domain, as defined in the preceding article, without liability for indemnity.

ARTICLE 12. All power plants which have, in whole or in part, been declared of public utility, and those under concession which do not have for their principal purpose the sale of power, may at all times dispose of excess power not utilized in the regular operation of the plant, under conditions fixed by the state council, on report of the minister of public works.

ARTICLE 13. Power plants already in existence, authorized under precarious and revocable title, and disposing of a gross primary horsepower in excess of 250 horsepower, or having for their principal object the sale of power, must within a period of five years from the date of passage of this act be placed under concession, by decree.

SECTION IV.

General provisions.

ARTICLE 14. Watercourses, or parts thereof, including canals of the public domain, to which this act shall apply are (1) those specified in the schedule accompanying the order of July 10, 1835, classified in conformity with other orders subsequent thereto; (2) those classified as a part of the public domain at the completion of works declared of public utility or following acts of redemption. Such watercourses and parts thereof and canals shall not be separated from the public domain except by enactment of law.

All claims based on rights acquired on watercourses under paragraph 1 of this article shall, under penalty of forfeiture, be instituted within one year from the date of passage of this act.

ARTICLE 15. The rental accruing to the nation from authorized power plants or those under concession shall conform to article 44 of the law of April 8, 1898, and to regulations made or to be made in execution of that law. By such regulations shall be fixed the special conditions governing rentals applicable to plants established on the canals of the public domain.

ARTICLE 16. Administrative regulations, based on report of the minister of public works, shall cover—

1. Form of water regulations for authorized power plants.
2. Form of articles of concession.

3. Forms for plans and specifications covering projects and their approval.

4. Procedure to be followed in connection with the various inquiries relative to concessions and authorizations for power plants, and in the establishment of rights of way.

5. Rules for national supervision of power plants under concession, the cost of which shall be borne by the concessionnaire.

6. General regulations covering the sale of surplus power, as provided in articles 5 and 12.

7. In general, all necessary measures for the execution of this act.

ARTICLE 17. This law shall not apply to power plants already in legal existence.

ARTICLE 18. All laws and regulations in contravention of this act are hereby repealed.

CHAPTER V.

REVIEW OF THE WORK OF THE BUREAU OF HYDRAULICS AND AGRICULTURAL IMPROVEMENTS OF THE FRENCH DEPARTMENT OF AGRICULTURE.[a]

ORGANIZATION OF THE BUREAU.

FUNCTIONS.

The waters of France, in their legal status, are divided into two distinct categories. Rivers navigable by ships or rafts form a part of the public domain and, if used principally for transportation, are under the control of the minister of public works. Watercourses navigable neither by ships nor rafts and springs, underground waters, etc., do not form a part of the public domain and are, according to their nature, subject to the more or less extended rights of the private individual. Their control is vested in the ministry of agriculture, which adopts and enforces measures designed to enhance their importance for agriculture and domestic supply.[b]

The policing, conservation, and management of these waters are under the control of the hydraulic service, a branch of the bureau of hydraulics. This bureau has been under the ministry of agriculture since its organization in 1881.

In 1903 the bureau was organized under the name of the bureau of hydraulics and agricultural improvements, and its duties and importance were considerably increased by adding to the hydraulic service the new office of "agricultural improvements." The manifold functions of the latter were established with a view, on the one hand, of insuring a better utilization of the waters by agriculturists, and on the other, of improving land for various rural enterprises.

Until 1903 the Government had limited itself to giving assistance to enterprises pertaining to agricultural hydraulics by granting sub-

[a] Circular of the department of agriculture.

[b] The total length of waters navigable by ships or rafts in France is about 7,980 kilometers (about 4,956 miles); the length of those not so navigable is about 270,000 kilometers (about 167,670 miles).

sidies for this purpose to corporate associations,[a] by undertaking the study of the most interesting projects of this nature, and, if the work was of very great importance, by having it supervised by government agents.

But such government assistance was always strictly limited to important canals and drainage works, the utilization of the water conducted to private properties being left entirely to the initiative of the individual. The result of this was that the farmers, left to their own devices and lacking the necessary knowledge and experience, failed to profit as much as was expected from the expenditures of the Government. Agricultural utilization of the waters did not develop as was hoped. The agricultural improvement service was created to remedy this condition by the organization of a technical force composed of agronomic engineers who would guide the syndicates and landholders in the rational management of the irrigated lands, in the choice of crops best suited to the soil, and in the practice of irrigation. It is also the duty of this service to study, in cooperation with the agents for roadways and bridges, the economic effects on agriculture of the great hydraulic works. It cooperates with interested parties in making various improvements on the land (drainage, making the land salubrious, construction of farm roads, etc.) and in every sort of enterprise pertaining to rural engineering (farm buildings, dairies, distilleries, etc.).

The reorganization of the bureau of hydraulics and agricultural improvements has increased its usefulness by inducing a better agricultural utilization of waters and by enlarging its sphere of action.

PERSONNEL.

The bureau of hydraulics and agricultural improvements comprises two distinct branches:

In the Departments[b] the hydraulic service is organized from officials of the office of bridges and roads (engineers in chief, engineers, superintendents, and clerks), under the direction of the inspectors general of the agricultural hydraulics. For the execution of any large work or for a very important study, special branches of the service may be organized from the office of bridges and roads, detached from the ministry of agriculture. Finally, special clerks for agricultural hydraulics are employed in Departments where the hydraulic service has a great deal of work to do.

The agricultural improvement service comprises an inspection force vested with the control and examination of projects before they

[a] The syndical [corporate] associations, which were established by the laws of June 21, 1865, and December 22, 1888, consist of groups of proprietors interested in the same enterprise of public interest. These associations can, under certain conditions and after complying with certain formalities, benefit under the statute of public utility.

[b] Administrative districts into which the French Republic is divided.

are submitted to the higher administration, a force of engineers in charge of territorial districts to make studies and draw up plans, and a force of technical agents to aid the engineers in their studies and in supervision of the works. In addition, professors of agriculture cooperate with this service in all things relating to agricultural research. Within the limits imposed by the necessities of their regular duties, they also aid the engineers and technical agents in the study and preparation of plans, and in the supervision and control of works.

COMMISSIONS.

To aid the administration in its examination of matters which have been studied by the Department services, a commission on hydraulics and agricultural improvements has been organized in connection with the bureau for the purpose of giving advice on technical and administrative matters submitted by the minister for examination. Reports are laid before this commission either by the inspectors general of hydraulics or by the inspectors of agricultural improvements, according to the nature of the matter.

In addition, two other commissions are charged with the verification of the accounts of the irrigation and drainage works to which the Government has granted an interest guaranty. A special commission decides on requests for subsidies to communal works for supplying drinking water, of which we shall speak later.

In conclusion, a decree of March 31, 1905, created in the bureau a committee to promote, coordinate, and centralize research on the numerous scientific problems relating to the improvement of the soil, and notably questions pertaining to the following subjects:

Physical and mechanical properties of the soil and their relation to their geologic origin.

Irrigation—the composition, action, and use of irrigating water.

Agricultural utilization of the refuse and waste waters of industrial establishments.

Research, selection, and culture of the best botanical species for introduction and propagation on irrigated land, poor and uncultivated soils, peat or boggy land, salt lands, and others to be improved.

Meteorology and agricultural physics.

The application of machines and motors in works of agricultural improvement and the utilization of electric power in agriculture and rural industries.

A second decree of December 26 of the same year, with a view of developing the study of hydrology, increased the membership of the committee and especially charged it with the study of the relations existing between precipitation and surface and underground run-off. Included also were the investigation of the various influences

affecting stream flow and the best methods of utilizing them for the development of power. The programme further embraced the examination of various questions relating to the circulation of underground waters and the regularity of springs, with a view to facilitating the utilization of their waters for public supply and laying the foundations for new legislation to insure good use of the hydraulic wealth contained in the subsoil of the national territory.

The foregoing remarks describe the organization and functions of the bureau of hydraulics and agricultural improvements. We shall now take up in detail the different functions of the branches of this bureau.

THE HYDRAULIC SERVICE.

FUNCTIONS.

The functions of the hydraulic service are manifold and complex, by reason of the diversity of government work, whose purpose it is to insure the best possible utilization of water in the interest of the general public. The Government uses various means to perform its mission effectually. It endeavors to encourage individual initiative and at the same time to prevent injury to the general public and even to the individuals. Where a projected enterprise is clearly for the public good, the Government takes the place usually assumed by private individuals.

The Government exercises this intervention through the hydraulic service, especially in policing, conserving, and controlling waters which do not form a part of the public domain.

The policing of the waters includes the removal of obstructions to the flow of water in channels by regular dredging and cutting of weeds and the regulation of the power and diversion dams to the end that floods shall be prevented and that no injury shall be done to the public water supplies, public health, and other general interests downstream. It also includes measures to prevent damage by pollution of waters by industrial wastes.

The Government intervenes in the adjudication of conflicting claims to water supply for agriculture and other industry, when the interests demand it. To insure the proper control and utilization of waters, the Government grants subsidies to defray the cost of conservation works undertaken by communes or corporate associations. The principal operations subsidized under these conditions are works of irrigation, reservoir and dam construction, drainage, channel rectification, bank protection, and the removal of silt deposits. Protection works are subventioned, even when the protection is from watercourses belonging to the public domain or the sea, whenever the agricultural interests involved are of sufficient importance to justify the intervention of the department of agriculture.

Finally, projects for municipal water supply constitute a special category of subsidized enterprises. Formerly, the subsidies were restricted to rural communes having a population of less than 1,000 inhabitants. The law of March 31, 1903, however, provided that a tax of 1 per cent should be levied on the total amount of money wagered at the race tracks, the proceeds to be used to subsidize communal projects to supply drinking water, with the restriction that this subsidy shall not be granted to cities where the value of the "centime" (municipal tax) exceeds 1,000 francs (about $200). The amount of the subsidy allowed in the execution of this law is determined by a computation based on the fiscal obligations of the commune and the per capita expense of the work. All subsidized enterprises must be approved by the minister of agriculture, who makes such modifications in the plans submitted to him as he deems necessary to insure their effectiveness. The execution of the work is under the control of the hydraulic service.

But the Government does not confine itself to subsidizing corporate associations. It undertakes, of its own motion, important works or those presenting special technical difficulties, and instructs the hydraulic service to take up studies that it considers useful or that have been requested by the communes or corporate associations. Generally a part of the expense must be borne by the parties interested. The hydraulic service, by suggesting the proper legislative measures and by pursuing the necessary studies and researches, endeavors to develop every method of utilizing waters likely to prove of benefit to the public. Thus it took up the modification of the law of June 21, 1865, relating to corporate associations, and the law of December 22, 1888, enacted through the efforts of the service, extended the benefits to a number of enterprises not included in the first law. The later law also changed the conditions relating to the majority necessary to constitute a corporate association. It facilitated the creation of associations to be organized for the purpose of executing works for the improvement of the soil, irrigation, drainage, etc. In effect, the law of 1865 required for the formation of these societies the unanimous consent of all the parties interested; the law of 1888 permits the majority to overrule the minority, provided the object of the association has been declared a work of public utility by the council of state.

In another line of effort, the hydraulic service has endeavored to encourage the development of hydro-electric power and its application to agricultural and other industrial purposes. Although numerous and important factories, run entirely by "white coal," have been erected for some years in the mountainous regions, notably among the Alps, it is recognized that measures must be taken to encourage their further installation. To this end on January 15,

1904, the minister of agriculture laid before the Chamber of Deputies a bill relating to power plants on nonnavigable streams. This measure was designed to facilitate the control of these watercourses, and also the utilization of their latent energy, while respecting the rights of riparian proprietors and the interests of irrigators.

A force has been organized to prepare an inventory of the unutilized resources of the watercourses in the Alps and the Pyrenees, and to seek methods of exploiting them. This hydrologic study is to be generalized and extended to the rest of the territory in order to amplify and improve previous studies of the volume and regularity of nonnavigable streams. Investigation will be made of the extent and regularity of subterranean waters and the flow of springs fed by them. These researches, which are important because of the daily increasing use of such waters for domestic supply, will form the basis of new legislation relative thereto.

The following review gives some idea of the principal work done by the hydraulic service and fittingly complements the preceding statement of its functions.

NOXIOUS WATERS.

DRAINAGE AND SOIL IMPROVEMENT.

Works of this nature are designed to improve the public health and to substitute cultivated fields for areas covered with water. These fields are usually very fertile, especially when irrigated. Works of this kind are usually constructed by the concessionnaires or by corporate associations, but many operations of considerable importance have been undertaken or are now projected by the Government.

Among the drainage works undertaken within the past thirty years may be cited the draining of the Fos marshes (Bouches-du-Rhône), and among the projects soon to be undertaken the draining of the pool of Arnel (Hérault).

Among the principal enterprises for soil improvement fully executed or terminated since 1870 must be mentioned the moors of Gascony (Gironde et Landes), covering an area of 800,000 hectares (3,088 square miles); the Sologne (Loiret, Loir-et-Cher, Cher) extending over 500,000 hectares (1,930 square miles); the Dombes (Ain), 112,700 hectares (435 square miles); and the Double (Dordogne), 50,000 hectares (193 square miles). Works for the improvement of the plain of Forez (Loire), which has an area of 60,000 hectares (232 square miles), are now in course of construction. This enterprise includes the building of an irrigation canal, which will enhance the value of the reclaimed lands.

The Government has contributed largely to defraying the cost of all these enterprises. The work has remarkably ameliorated the

conditions of human life in these regions and has at the same time greatly increased the territorial wealth of the country. Take, for example, the moors of Gascony; the average price of the land per hectare has risen from 65 to 270 francs ($13 to $54); the average length of life, formerly 34 years and 9 months, is now 39 years, a higher average than that for the whole country. The pines of Landes, which cover immense tracts of improved lands, have added to the wealth of the country by the commerce in timber, resin, etc., to which they give rise. The general well-being is increased and there has been a notable growth in the public revenues.

In Sologne the moors, which were formerly uncultivated, are today covered with woods over an area of more than 250,000 hectares (965 square miles). Since the beginning of the works the population of Sologne has increased 20 per cent, while that of neighboring regions has grown only 10 per cent. In the Dombes country, formerly the most unhealthful region in France, the work of improvement has resulted in diminishing the fever cases by five-sixths. Similar results have been obtained on the plain of Forez, where, thanks to irrigation, land values have increased enormously.

There is one enterprise now projected and soon to be begun, if Parliament grants the necessary funds, with which, so far as the results to be obtained are concerned, only the improvement of Landes can be compared—that is, the drainage of the east coast of Corsica. This is a vast project, which includes the filling up and drainage of insalubrious marshes and pools and the improvement of the mouths of rivers. This work is to be completed by the construction of a system of canals for the conveyance of good drinking water, so indispensable to the health of the communes interested. When the work is completed we may expect a transformation of a region now devastated by malaria extending over more than 100,000 hectares (386 square miles).

CLEANSING AND STRAIGHTENING WATERCOURSES.

These operations, which are necessary to insure the free flow of waters and which have considerable influence on the salubrity of river lands, are particularly delicate and require the constant attention of the hydraulic service. The importance of the work accomplished is demonstrated by the length of the streams annually cleaned, which extend over more than 13,000 kilometers (8,080 miles) and drain an area of more than 420,000 hectares (1,622 square miles). Sometimes it is necessary to complete the work of cleaning and weed cutting by straightening and deepening the channel. As an instance we may point to the work recently done on the Conie (Eure-et-Loir), which covered more than 150 kilometers (93 miles) of the river.

DAMS AND PROTECTION OF BANKS.

This work, by which lands of great value are preserved and brought under cultivation, serves also in certain cases to protect dwellings. The work is done by corporate associations, with important subsidies from the Government. The most important enterprises of this nature have been completed in regions exposed to the ravages of torrents, such as the Jura, the Pyrenees, and the Alps.

But it is not only against river waters that we must protect cultivated lands. The sea also commits depredations, and important dike work has been undertaken to restrain its incursions. In this connection the repair of the dikes encircling the salt marshes of Guerande may be cited. This great enterprise, which has cost not less than 300,000 francs (about $56,000), will preserve to the salt industry an important area, which was menaced by the encroachments of the sea.

USEFUL WATERS.

IRRIGATION AND SUBMERSION.

The hydraulic service has directed its efforts principally to the development of irrigation of lands not bordering on rivers. Such lands can be watered only by the construction of irrigation canals. These are built either by corporate associations or by associations of concessionnaires. The Government subsidizes such enterprises, leaving, however, a large part of the expense to be borne by those interested.

Since 1870 eight large irrigation canals have been constructed, with a delivering capacity exceeding 1,000 liters per second (35 second-feet). Twelve more large canals were projected and are now completed or about to be completed.

In addition to canals for watering the land must be mentioned those for the submersion of vineyards, constructed in the Department of Aude between 1880 and 1890, after the invasion of phylloxera. These canals are designed to enable the vine grower to keep his vines under water in winter to a depth of 30 or 40 centimeters (0.98 to 1.31 feet) for a period of forty to sixty days. The canals of Aude serve a vineyard area of 11,000 hectares (42.5 square miles), of which 7,225 hectares (27.9 square miles) have been submerged since the completion of the work. They were built by the Government at a cost of more than 5,000,000 francs ($1,000,000) and were first put under the charge of the corporate associations interested, but were finally transferred to them entirely on condition of the payment in annual installments of two-thirds of the cost price advanced by the treasury.

The irrigation canals proper are situated in the arid region of the southeast. Irrigation alone renders possible truck gardening and

the culture of fruits and flowers, which are shipped as far as Paris. Flowers for perfumery are cultivated on a large scale in the Departments of Var and Alpes-Maritimes. The market for aromatic flowers in the city of Grasse owes its importance wholly to the proximity of the Siagne canal.

Finally, the service will study the question whether it will not be profitable to extend irrigation projects in certain regions by pumping water to fields not susceptible of irrigation by gravity canals. It is possible that, by selling the surplus power thus obtained, water can thereby be supplied for agricultural purposes at a price more commensurate with the returns from the land.

INCREASING THE REGULARITY OF STREAM FLOW.

In the Midi, where irrigation is especially well developed, the volume of the streams is frequently insufficient in the dry season to meet all the requirements of irrigation. Although the quantity of water allowed to each irrigator has been reduced to bare necessity, it frequently happens that the lack of water brings ruin to agriculture. This distressing condition is remedied by the construction of reservoirs in the more elevated parts of the valley in which considerable quantities of water are stored up in times of plenty for use when the dry season sets in. These works are important for another reason. By regulating the volume of the streams, they increase the available water power in the streams below.

Among the operations of this kind is included the regulation of the volume of the streams flowing from the plateau of Lannemezan (upper Pyrenees). This regulation is accomplished by means of a canal which draws water from the river Neste. As the Neste was not of sufficient volume to assure at all times a sufficient flow in the canal, the Government had to supplement its volume artificially. For this purpose the lakes of Oredon, Caillaouas, Aumar, and Cap de Long, situated in the Pyrenees, have been transformed into reservoirs. During the dry season the waters from these lakes are diverted into the Neste.

MUNICIPAL WATER SUPPLIES.

As has been said above, under the law of March 31, 1903, a tax of 1 per cent is levied on the money put up in wagers under certain conditions, and from the sums thus collected subsidies are granted to communes who apply for them for the construction of aqueducts for drinking water. The applications for subsidies are submitted to the special commission mentioned above, which approves them after a thorough investigation of the projects by the agents of the hydraulic service. This examination covers several entirely distinct subjects.

First, the hydraulic service must ascertain under what conditions and with what restrictions the contemplated conveyance can be authorized, in order to determine whether it shall or shall not be subsidized. This is indispensable, as by law the rights and interests of all users of the waters from which the supply is to be derived must be safeguarded. Also, the engineers of the hydraulic service are required to verify every detail of the enterprise; to see whether the plans are technically correct and well adapted to accomplish the end in view; and, finally, to determine whether the work is planned as economically as possible.[a] After these data have been obtained in the field the bureau of hydraulics and agricultural improvements submits the projected enterprise to its technical advisers for another examination. If advisable, it takes the necessary steps to have the enterprise declared of public utility, and finally gives to the commission on subsidies a full and clear statement of all the facts.

The subsidies are paid to the communes in installments proportioned to the expense actually incurred, after it has been proved that the work has been properly done and that no modifications have been made in the plans whereby their value might be impaired.

After the experience of three years we may safely assert that the law of March 31, 1903, has resulted in a considerable increase in communal enterprises for the conveyance of drinking water, and that the effect on public health has been most gratifying.

REGULATIONS FOR FACTORIES.

The number of factories annually regulated is large, about 580. In recent years this regulation has been particularly important because of the increased number of large factories using much power. The operations of these establishments greatly influence the regularity of the streams and necessitate the building of very high dams. In addition to supervising the conditions affecting the flow of the water and the health of the community, the administration, by virtue of its police powers, sees to it that the structures are so strongly built that all danger therefrom to dwellers downstream is removed.

THE AGRICULTURAL IMPROVEMENTS SERVICE.

By the terms of article 1 of the decree of April 5, 1903, cited above, the principal improvement works which the service has undertaken are as follows: (1) Agricultural utilization of waters; (2) drainage and improvement of the soil; (3) redistribution and exchange of parcels of lands and farm roads; (4) construction of rural buildings, small agricultural industries, and other land improvements.

[a] In addition to their duty as supervisors, the engineers of the service are at the command of the communes to prepare, on request as communal engineers, all plans for the installation of domestic water supply.

AGRICULTURAL UTILIZATION OF WATERS.

At present most farmers confine their efforts to constructing canals, ditches, etc., and do not interest themselves sufficiently in the rational management of the surfaces irrigated or in the distribution of water in conformity with seasons and crops. They do not introduce sufficient system into their irrigation work. As each farmer irrigates at will his own parcel of land, sometimes uselessly and often at cross purposes with his neighbor, they frequently obtain poor results, entirely disproportionate to the expense incurred, and waste, to their own and to others' injury, the water at their disposal. In order to avert such misuse, the agricultural improvements service acts as guide to the farmers. It prepares the plans for the proprietors or syndicates, and in this way completes the work of the hydraulic service. This aid is given not only to cultivators desiring to utilize the waters supplied by the large irrigation canals, but also to those who wish to make direct use of the small streams. Some idea of the importance of this work may be realized if we note that after deducting from the water in our rivers the amount necessary for food and domestic purposes, sufficient volume remains to irrigate 12,000,000 hectares (46,320 square miles), putting the irrigation at 15,000 cubic meters per hectare (4.92 acre-feet per acre) a year, the generally accepted average. In this connection it may be remarked that the little streams which the farmers can use directly are of considerable importance. Those having an average length of 2 to 5 kilometers and a basin of not more than 2,000 hectares (7.7 square miles) represent about 85 per cent of the watercourses of our country.

DRAINAGE AND IMPROVEMENT OF THE SOIL.

The theory and practice of drainage have made important progress in recent years, and the methods of subterranean drainage, invented about the middle of the last century, have also been much improved. The art of the drainer at first covered a few practical rules, but it has gradually developed until now we have a fairly complete system which enables us to substitute rational processes for old empirical methods. These processes have become more definite and economical and insure constructions of almost limitless duration. Under these conditions it is evident that drainage to-day constitutes a special art, possessing its own peculiar technique and requiring deep study and preliminary apprenticeship. The study of such projects, as well as the supervision and direction of the works, has been intrusted to the agricultural improvements service.

Special privileges relating to the flow of waters were granted to drainage enterprises by the law of June 10, 1854. Another law of

July 17, 1856, brought in by the Government, appropriated the sum of 100,000,000 francs ($20,000,000) for loans to drainage works. By the terms of an agreement concluded April 28, 1858, between the minister of finance and the minister of agriculture and Crédit Foncier, the latter assumed the burden of these loans. The loans, bearing 4 per cent interest, are payable in twenty-five annual installments of 6.41 per cent of the sum, the borrower having the right to pay back the whole or a part at any time during that period. The payment of these installments is secured in the same manner as are the direct taxes. To cover these loans the Crédit Foncier has a lien on the crops and the right to take a mortgage on the drained lands. Ordinarily the Crédit Foncier contents itself with a mortgage without having recourse to the formalities necessary to insure its rights.

This legislation in favor of drainage enterprises is justified by the importance to agriculture of this form of land improvement. According to a report made in the name of the superior commission on the control of waters, organized in 1879 in the ministry of public works by M. de Freycinet, there were in France not less than 4,000,000 hectares (15,440 square miles), which could be drained to advantage. The area was probably even larger, as a statement contained in the law of April 17, 1856, estimates it at not less than 9,000,000 hectares (34,740 square miles).

REDISTRIBUTION—FARM ROADS—REMAKING THE CADASTER.

The agricultural disadvantages resulting from the parceling out of the land into small units caused the Government to take up the question of redistribution. The minister of agriculture summarized the advantages which would result from combining these small parcels, as follows: Economic employment of improved implements, impossible of use on separate small units of land; easy supervision of cultural operations; easy access to roads; independence of neighbors in the distribution of crops; facility of transportation; easy determination of boundaries; simplification of the ground plots of property; reduction of the cost of cultivation; possibility of cooperation in drainage, irrigation, dams, and straightening watercourses; repair of roads, etc.

Free exchange was facilitated by the law of November 3, 1884, which in certain cases reduces the proportional dues from 6.7 francs to 0.20 franc per hundred ($1.34 to 4 cents). But these isolated exchanges are by no means so important as a general rearrangement of boundaries, which can be accomplished only by the corporate associations, established in conformity with the laws of June 21, 1865, and December 22, 1888. It is to be hoped that the passage of the law of March 17, 1898, which was completed by the decree of June 9, 1898, and of the fiscal law of April 13, 1900, articles 19 to 21,

designed to hasten the revision of the cadaster, will enable us so to profit by this operation that the improvements hitherto described may be made at very little expense. Certain modifications must be made in existing laws to secure full benefit from the measures already passed by Parliament. The organization of the agricultural improvements service in the ministry of agriculture is a long step toward this accomplishment. The work is further aided by the agreement of 1904 with the office of direct taxes, through which the cadastral service and the agricultural improvements service can cooperate in the necessary operations.

From now on the agricultural improvements service will engage in systematic construction of farm roads, which will not diminish the land parcels, but will minimize the disastrous consequences of the parcel system. These roads can be built at a moderate cost, and the work entailed can be put under the control of free or commissioned corporate associations. The advantages that would accrue are as follows: They will supply outlets for the land parcels, thus giving right of way to both the principal and the dependent properties, and by so doing removing a pregnant cause of vexations and lawsuits. They will open to cultivation closed-in lands, which have been left uncultivated because of the impossibility of cultivating at the desired period. Finally, they will enable the intelligent farmer to cultivate when and as he wishes and give him freedom in the distribution of his crops.

RURAL BUILDINGS.

The construction of farm buildings and the erection and management of industrial establishments as an adjunct to the farm necessitate an ever-increasing fund of special knowledge which is rarely possessed by any one person. In fact, the people usually engaged in putting up farm buildings are not progressive, either in France or elsewhere, and are not in touch with the improvements in agricultural industries and industrial equipment. At this time, when new methods of culture and economic necessities often render imperative a complete change of agricultural equipment, the small farmers find the agricultural improvements service an invaluable aid. They can call in the aid of this service whenever they want to utilize the power of a waterfall for the generation of electric power, and apply the energy to numerous agricultural uses, such as the lighting of farm buildings and the operation of various agricultural apparatus, such as thrashing machines, crushers, grinders, churns, saws, etc.

This use of electricity in many cases transforms farm operations and facilitates the development of small rural industries.

The service also renders very important aid in the construction of cooperative buildings. The small farmers, who by force of circum-

stances are compelled to resort more and more to cooperation in farming operations, need establishments of a truly industrial character. Very often when a question arises concerning the erection of a building and its interior arrangement they lack the knowledge to estimate the expense involved and the profits to be derived and to make the necessary plans. They can call on the service, however, to study and prepare the plans, and thus they receive the moral and material support they need. These projects relate to dairies, cheese dairies, distilleries, caves, cellars, granaries, refrigerating plants for farm products, and all other cooperative establishments.

IMPROVEMENT OF POOR OR UNCULTIVATED LAND.

Waste lands, moors, pasture commons, heaths, marshes, bogs, etc., cover a considerable area in France, amounting, according to the agricultural statistics of 1892, to 6,226,185 hectares, or 11.77 per cent of the total area and 12.336 per cent of the agricultural land. Forestation is the only possible method of utilizing a large part of this area, especially the rocky soil and mountain lands. Other lands, on the contrary, such as moors, heaths, marshes, etc., can be made valuable by drainage, clearing, breaking up, etc., and by the building of roads to permit transportation of the necessary fertilizers and other important adjuncts to agriculture.

We may mention, in the category of lands capable of agricultural utilization, peat soils proper, to which must be added a large number of more or less peaty pockets formed by vegetation whose decomposition is not sufficiently advanced to form real peat. Such deposits are found everywhere, especially in the granitic soils of the Vosges, Morvan, the central plateau, Brittany, etc. These lands, if given the proper drainage and cultivation, would in many localities give large returns.

There are difficulties in the improvement of another kind of soil, the salt marshes. The agricultural improvements service has several times had to take up the very complex problem of bringing Camargue under cultivation, this island in certain places requiring methodical desalting in addition to improvement by drainage.

MISCELLANEOUS IMPROVEMENTS.

In addition to the works enumerated above, we must mention among the subjects engaging the attention of the agricultural improvements service the agricultural utilization of refuse and residuary waters from industrial establishments, the water supply of farms and rural exploitations, the construction of cables for facilitating or rendering possible the exploitation of land difficult of access, etc.

METEOROLOGY.

The bureau of hydraulics and agricultural improvements has under its charge all functions pertaining to agricultural meteorology. It subsidizes various meteorologic stations and interests itself particularly in the use of ordnance as a protection against hail, which is becoming a general practice throughout France. It grants subsidies to associations organized for protection against hail, frost, and other inclemencies of weather injurious to crops.

In spite of the increasing confidence of the rural population in the efficiency of ordnance as a protection against hail, the effectiveness of this method has not yet been fully established. Very diverse engines are used for this purpose, namely, cannon, rockets, bombs, petards, and many others, all of which have their partisans. The committee of the bureau of hydraulics and agricultural improvements is studying the subject scientifically and making experiments to determine the value of this method of defense and the relative value of the various engines used.

CHAPTER VI.

WATER-POWER LEGISLATION IN THE UNITED STATES.

By M. O. Leighton.

FEDERAL STATUTES AND POWERS.

EFFECT OF THE DESERT-LAND ACT.

The authority of the Federal Government over waters within the United States is of two kinds—by right of sovereignty and by right of proprietorship. The sovereignty is generally believed to be limited, except in the Territories, to the right to use designated streams and watercourses for purposes of commerce. Such limited sovereignty was given to the United States by the eighth section of Article I of the Constitution. All things necessary to the maintenance and improvement of navigation of these waters are subject to the absolute control of the Federal Government, but with this the sovereignty apparently ceases. This point is, however, not well settled. There is considerable disagreement as to the limitation that may be placed upon the scope of the commerce clause. It is contended by a few that the authority is confined to the local adjustment and control of navigable channels, while others hold that the control extends to the uttermost tributaries in a drainage area, if such control is necessary to the regulation of the channels actually used for transportation. The latter appears to be the view of the Supreme Court of the United States. (United States *v.* Rio Grande Irrigation Co., 174 U. S., pp. 690–710.)

The authority of the Federal Government over waters by right of proprietorship persists only where the Government is an actual proprietor of land bordering watercourses, as in the public-land States of the West. It is commonly believed that in such cases the Federal Government is subject, in common with all other proprietors, to state water laws. The waters of the public domain belonged originally to the Federal Government, but the usufruct thereof was conveyed by statute from time to time as the land was settled and sovereign States were organized. The rights of appropriation and use of the waters of the public-land States was conveyed to the people by an act of Congress entitled "An act to provide for the sale of desert lands in

certain States and Territories," approved March 3, 1877 (Stat. L., vol. 19, p. 377). The part of the act referred to is as follows:

Provided, however, That the right to the use of water by the person so conducting the same on or to any tract of desert land of 640 acres shall depend upon bona fide prior appropriation; and such right shall not exceed the amount of water actually appropriated and necessarily used for the purpose of irrigation and reclamation; and all surplus water over and above such actual appropriation and use, together with the water of all lakes, rivers, and other sources of water supply upon the public land and not navigable, shall remain and be held free for the appropriation and use of the public for irrigation, mining, and manufacturing purposes, subject to existing rights.

The effect of this law is set forth in an opinion of the supreme court of the State of Oregon, as follows:

Annie C. Hough et al. v. S. A. D. Porter et al.

Opinion by Mr. Commissioner King.

The principal contention of appellants as first urged was that the court acted without jurisdiction in directing that all persons interested in the lands bordering on Silver Creek, its tributaries and channels, be made parties to the suit, and that such action on the part of the court constituted reversible error. These questions of practice, with matters incidental thereto, were determined adversely to counsel's contention (95 Pac., 732), and the cause was set down for further argument on the main points involved, principal among which is that of riparian rights, as affected by the act of Congress of March 3, 1877, known as the desert-land act: *ib.*, 752. This question and the points formerly determined were fully discussed at the reargument. After a reconsideration of the questions of practice presented we find no reason to depart from the conclusions announced in our former opinion.

We come then to a consideration of the desert-land act, as to its effect upon the parties hereto owning lands upon the streams involved, the rights of each of whom have attached since the passage of the act. This confronts us with the legal problem as to whether any are riparian owners; and, if so, to what extent and what bearing their claims as such have upon the water rights in question.

It has become a matter of history that prior to any laws upon the subject the use of water was exercised under a custom permitting any person to go upon a stream, or other source of water supply upon the public domain, and divert water therefrom wherever and whenever needed, provided the use thereof did not interfere with the prior rights of others. In other words, priority in the diversion and use determined the rights of all conflicting claimants. This procedure was encouraged and acquiesced in by the Government for many years throughout the Pacific coast States, until in recognition thereof the act of Congress of July 26, 1866 (7 Fed. Stat. Ann., 1090), was adopted, which provided:

"Whenever, by priority of possession, rights to the use of water for mining, agricultural, manufacturing, or other purposes have vested and accrued, and the same are recognized and acknowledged by the local customs, laws, and the decisions of courts, the possessors and owners of such vested rights shall be maintained and protected in the same; and the right of way for the construction of ditches and canals for the purposes herein specified is acknowledged and confirmed * * *"

This act constituted a recognition of preexisting rights rather than a creation of any new one, and accordingly recognized and assented to appropriation of water in contravention to the common-law rule as to continuous flow: Broder *v.* Water Company, 101 U. S., 274; United States *v.* Rio Grande Irr. Co., 174 U. S., 690; Gutierres *v.* Albuquerque Land Co., 188 U. S., 545; Davis *v.* Chamberlain, 51 Or., — (98 Pac., —).

Supplemental to the above act, provision was made by Congress July 9, 1870, for incorporating a reservation in favor of such rights in all patents when issued, as follows: "All patents granted or preemption or homesteads allowed shall be subject to any vested and accrued water rights or rights to ditches and reservoirs used in connection with such water rights, * * * :" Rev. Stat., 2340. This was followed on March 3, 1877, by what is known as the desert-land act, parts of which, in so far as material to this discussion, are:

"That it shall be lawful for any citizen of the United States, or any person of requisite age 'who may be entitled to become a citizen, and who has filed his declaration to become such,' upon payment of twenty-five cents per acre, to file a declaration under oath with the register and receiver of the land district in which any desert land is situated, that he intends to reclaim a tract of desert land not exceeding one section, by conducting water upon the same, within the period of three years thereafter: *Provided, however*, That the right to the use of water by the person so conducting the same, on or to any tract of desert land of six hundred and forty acres shall depend upon *bona fide* prior appropriation; and such right shall not exceed the amount of water actually appropriated, and necessarily used for the purpose of irrigation and reclamation; and all surplus water over and above such actual appropriation and use, together with the water of all lakes, rivers, and other sources of water supply upon the public lands and not navigable, shall remain and be held free for the appropriation and use of the public for irrigation, mining, and manufacturing purposes subject to existing rights * * *": 19 Stat. (U. S.), 377; 6 Fed. Stat. Ann., 393.

The title of the foregoing act reads, "An act to provide for the sale of desert lands in certain States and Territories." Being an act of Congress, it is well known that it is not required that the title of the act embrace all its provisions. And, while a different rule prevails in some of the States, it is probably an exception rather than the rule that acts of Congress are limited to matters contained in their title. This being the rule which prevailed in Congress, we have only to look to the body of the act to ascertain its intention. After providing for the reclamation of arid lands and for the procuring of title thereunder, it will be observed that, in this act, as essential to the reclamation of lands, the water right, when located by the persons taking the land, shall depend upon *bona fide prior appropriation.* The reason for this is apparent; the object and purpose of the act was by this method to reclaim, develop, and make productive arid lands or those of a desert character, which, as a rule, were nonriparian.

For many years it was an open question whether lands through which streams flowed in the natural channels were subject to reclamation under this act: Sims *v.* Phalen, 11 L. D., 206. But it was finally determined that such lands could be reclaimed where clearly shown to be of a desert character: Houck *v.* Bettelyoun, 7 L. D., 425; Nilson *v.* Anderson, 23 L. D., 139. Considering this feature with the then long-existing conditions in reference to the public lands throughout the West, the reasons for providing that the water rights should be acquired under the doctrine of prior appropriation are obvious.

The first act (1866) refers to priority of possession and local customs, rules, regulations, etc., to which rules of construction were soon applied, the outcome

of which depended largely upon whether the decisions were by courts in localities of a strictly arid nature or in the humid States. If in a strictly arid section, the doctrine of prior appropriation prevailed; while, if humid, a middle ground, or what is called "the modified doctrine of riparian rights," appears to have been the one adhered to and deemed the most conducive to the public welfare. Near the time of the passage of this act conflicts had arisen from the application of the law, as applied to riparian rights, in the arid and semiarid West. In California the effect thereof on riparian rights was involved in much doubt and not fully determined, while in Nevada the noted case of Vansickle *v.* Haines (7 Nev., 249) had been decided, adhering to the common-law rule on the subject. This latter case, however, was subsequently overruled, since which time the doctrine of prior appropriation has there prevailed: Jones *v.* Adams, 19 Nev., 78; Reno S. Works *v.* Stevenson, 20 Nev., 269; Walsh *v.* Wallace, 26 Nev., 299.

The act of 1866 had left somewhat in doubt not only the question of its effect upon riparian rights, but an uncertainty whether it thereby intended to establish a permanent rule upon the subject. And the act of 1870, requiring reservations in all patents issued, by inserting a statement therein to the effect that the patents were executed subject to vested and accrued water rights, etc., was evidently intended as a precautionary measure to remove doubts then extant as to the legal effect of any patents subsequently issued, so far as applicable to any rights acquired before the date thereof.

In order, therefore, to remove such doubts and to establish a uniform rule throughout the States mentioned in the act, whereby all appropriations made from streams flowing through public lands over which Congress had power to legislate, after the provisions specifying the manner in which lands taken under the act could be reclaimed, there was added the clause:

"And all surplus water over and above such actual appropriation and use, together with the water of all lakes, rivers, and other sources of water supply upon the public lands, and not navigable, shall remain and be held free for the appropriation and use of the public for irrigation, mining, and manufacturing purposes, subject to existing rights:" 19 Stat. (U. S.), 377.

This reservation of water rights for the benefit of the public was clearly not essential to any of the other provisions of the act. The previous statement contained sufficient to define and protect the rights of those selecting lands under the desert-land act, but the added proviso, or something of similar import, was essential to the establishment of a clear and uniform rule upon the subject as regards all appropriations thereafter to be made from streams or other bodies of water upon the public lands and to which such might be riparian.

The words "shall remain and be held free for the appropriation and use of the public for irrigation," etc., are clearly words of reservation and dedication, and obviously so intended. It is insisted, however, that the language quoted is insufficient for either a grant, trust, or dedication; that a grant presupposes a grantee capable of receiving it; that it is not a trust because all three essentials necessary to constitute a trust, i. e., trustee, trust *res*, and *cestui que* trust, are wanting; that it can not be held to be a dedication, in that the right there alluded to is not an easement but is usufructuary only, partaking of the nature of real estate—an incorporeal hereditament, analogous to a "profit" in land, in that it depletes the riparian right. It is further observed that a dedication is not a grant and can not arise by grant, since it exists in favor of the entire public, in respect to which it was asserted, as above stated, that it can not become a grantee.

A dedication is defined as being in the nature of a gift, inuring to the benefit of the public as a grant, but differing from a grant in that no grantee *in esse* is necessary to its validity: 9 Am. and Eng. Ency. Law, 21; 13 Cyc., 439. It consists of devotion or giving of property for some proper object and in such a manner as to conclude the owner: State ex rel. Sims *v.* Otoe County, 6 Nebr., 129, 133; Patrick *v.* Y. M. C. A., 120 Mich., 185, 193.

A "reservation" as here used is something taken from the whole thing, covered by the general terms making the grant, and cuts down and lessens it (or act, under which title to the *res* from which the reservation may be made) from what it would be except for such reservation: Words and Phrases, p. 6140; Weynand *v.* Lutz (Tex. Civ. App.), 29 S. W., 1097. The latter term applied here: the National Government by its various laws relating to public lands granted to its citizens the privilege of acquiring title thereto. Construing all together as one act, the desert-land act by the language used appears to reserve therefrom to the entire public the right of any citizen after March 3, 1877, to divert, use, and acquire a right in and to the unappropriated waters flowing through, or adjacent to, any lands, thereafter patented, such right to be determined by priority. Reservations of this class may be found in Calhoun Gold Min. Co. *v.* Ajax Gold Min. Co., 27 Col., 1 (59 Pac., 607, 615; 50 L. R. A., 209; 83 Am. St. Rep., 17); Wilcox *v.* McConnel, 13 Peters, 496; Wilson *v.* Higbee, 62 Fed., 723. It would not be seriously questioned that such a reservation might be expressly and effectively made in a deed or other evidence of title. Then when we take into consideration that to determine the extent of the title received through a conveyance of any kind from the Government, whether by grant, patent, or otherwise, we must look into all acts in force in reference to the lands intended thus to be conveyed, to ascertain what interest remains subject to transfer, it becomes manifest that there is no difference in principle between a reservation resulting from an act in force at the time and an express reservation in the instrument itself through which title may be asserted.

It would seem, however, that as to what may be the proper term by which any interest thus reserved may be designated, we need not inquire. Nor is it material whether any term has been recognized or established by the courts to cover the privileges and rights reserved or surrendered by the Government to the public, or individuals of which the public is composed. Our form of government, Constitution, and powers reserved to the Government have necessarily given rise to privileges and rights not fully covered by the common law or by the terms in common use under it.

The right of the Government to dispose of its public lands and to deal with all rights incident thereto, in such a manner as it may deem best, has long been fully established and recognized by all decisions upon the subject. True, it can not by legislation determine for any State after its admission what the local laws relative to riparian rights shall be (United States *v.* Rio Grande Irr. Co., 174 U. S., 690, 703), but the General Government in dealing with its public lands may provide for their transfer as might any other landed proprietor and make such reservations therefrom by grant, dedication, or otherwise as it may see fit. Riparian rights may become the subject of a grant or dedication and may be severed from the soil: Coquille Mill and M. Co. *v.* Johnson (Or.), 98 Pac., 132. This principle is clearly and concisely stated in an opinion by Knoeles, district judge, in Howell *v.* Johnson (89 Fed., 556, 558), as follows:

"Being the owner of these (public) lands, it has the power to sell or dispose of any estate therein or any part thereof. The water (in question) is an innavigable stream flowing over the public domain, is a part thereof, and the

National Government can sell or grant the same, or the use thereof, separate from the rest of the estate, under such conditions as may seem to it proper."

Decisions to the above effect are too numerous and too well understood to need extensive citation.

By the homestead and other land acts Congress granted to citizens of various States and Territories the right at any time hereafter to enter upon the public domain and to select a quantity of land, in the manner there specified, and of thereby securing a home, notwithstanding no certain individual was designated to accept and receive such title. The effect of these acts was that the grantor of the public lands, the National Government, was to hold these lands in trust for the public, to be acquired by any qualified citizen thereof on compliance with the rules prescribed. Numerous grants *in præsenti* were also made, to be held in trust by States designated in such grants for any company, person, or persons who might construct any wagon or other roads there indicated. For example: A grant was made to the State of Oregon of alternate sections of public lands, designated by odd numbers, three sections per mile, to be selected within 6 miles of what was, at the time of the passage of the act, an imaginary road between two given points within the State, upon the doing of certain acts thereafter to be performed, thus reserving to the builders, if any there might be, the right to select the odd section desired: 14 Stat. (U. S.), p. 89, c. 174; Cahn *v.* Barnes, 5 Fed., 326; United States *v.* Dalles Military R. Co. (and seven others), 140 U. S., 599; s. c. 42 Fed., 351; 55 Fed., 711. Such a road in time became a certainty; and more than thirty years after the passage of the act lands were selected, in reference to which it has been held that upon selection thereof the right thereto relates back to the date of filing the map of definite location of the road, shutting out all intervening claims and settlements, regardless of patents issued to settlers thereon during the meantime—and this, too, notwithstanding such policy was instrumental in holding in abeyance and withdrawing from settlement large tracts of the public domain for more than a quarter of a century: Eastern Oregon Land Co. *v.* Brosman, 147 Fed., 807. Any settlers on such lands are held to have entered thereon with full knowledge of the law and to have taken them subject to the "contingent interests" in the land of such possible road of such company as might become the beneficiary of the grant: Altschul *v.* Cittings, 102 Fed., 36, 38.

Another and more apt illustration is that of the policy of the National Government respecting its mineral lands, in regard to which any one acquiring title to any part of the public domain under the homestead or under any other act takes such land subject to the exception that he does not acquire title to the minerals known to be therein at the time of entry or of patent, whether located for minerals at the time of the inception of the rights of its grantee or not: 5 Fed. Stat. Ann., 2318, 2319; Calhoun Gold Min. Co. *v.* Ajax Gold Min. Co., 27 Col., 1. The minerals may remain unclaimed for many decades, yet the first mineral locator, whether on patented lands or not (if the land patented was known to contain the minerals at the time of entry), upon full compliance with the law on the subject, may become the owner thereof. The same privilege is extended to the patentee, but, under the law, if he neglect to exercise his rights in this respect, he loses to him who becomes the first locator.

It was in the exercise of a similar prerogative on the part of the Government that there was by the act of 1877 given to the public, or to any individual thereof, the right to appropriate and apply to a beneficial use the waters flowing through its public domain. No limit as to the time in which this right may be exercised is made, except in effect that he who first diverts the water and with due diligence applies it to the uses there enumerated is given the better right thereto. It can make no difference, therefore, whether it be termed a grant,

reservation, dedication, trust, or other privilege; this unquestioned power of the owner over the public domain was exercised, and any one entering upon, and acquiring title to, any part of the public domain after the passage of this act accepted such land and title thereto with full knowledge of the law under which the patent was issued, the import thereof being that this right incident to the soil was reserved by the Government to be held in trust for the public; and that he who first applies the water to a beneficial use shall become the owner of the right thereto; and that the recipient of such title takes it subject to that right, which he, in common with others of the public, is privileged to exercise. It is elementary that the grantor can convey no greater title than he has. This rule as applied to cases of this nature is clearly and concisely stated in Hume *v.* Rogue River Packing Co. (51 Or.), 92 Pac., 1065, 1067. There the plaintiff was owner of a grant from the State, either directly to himself or by *mesne* conveyances to others, of all the tide lands bordering upon the river, as well as of all the uplands adjacent to the river above tide water, the title to which was acquired from the United States, and the description of which ran to the meander lines. In discussing this feature, this court, by Slater, C., says:

"He has no title by express grant from the State to any part of the bed and stream as such, but he does claim title to the entire bed of the stream at the mouth of the river where, by reason of the shifting of the channel of the river from north to south, and vice versa, and by successive purchases from the State as tide land of the uncovered sands on both sides of the river, his deeds overlap, and apparently, at least, he is, at that point of the river, the owner of the bed of the stream; but this fact, we apprehend, will be of no avail in support of his claim of ownership of the water when flowing over such land, for in any event he could acquire no greater rights thereby than would be given the ordinary and legal effect of such deed by virtue of the statute authorizing its execution and delivery."

It is true that the act of 1870 made it necessary to insert in the patents a reservation of all vested and accrued water righs, rights of way, etc., as well as to make similar reservations in patents respecting minerals; but, as stated, so far as a legal effect of the reservation is concerned, such would have been unnecessary, in that the Government could grant no greater right than it had. Acts of this nature, like those requiring patents to be issued for lands acquired under railroad and other grants, under which title passes by virtue of the acts granting the lands, are but supplemental legislation. In this manner the evidence of title may more conveniently be placed on record, and thereby add to the convenience, in many respects, of the holder of the title, but otherwise adds nothing thereto: Cahn *v.* Barnes, 5 Fed., 326, 331; Pengra *v.* Munz, 29 Fed., 830, 835; Langdeau *v.* Hanes, 21 Wall., 521; United States *v.* Dalles Military R. Co., 140 U. S., 599; also cases cited in Rose's Notes (U. S.), vol. 8, p. 466.

A good illustration of the power of the Government or other landed proprietor, at all times and whenever desired by it, to grant, reserve, or dedicate a right to any one at any time to acquire title to all or to any part of its public domain in such manner as it might designate—either to the land itself or to the incorporeal rights appurtenant thereto, whether an easement over it, the removal of the minerals, of the timber, or of the right to the use of all or any of the waters flowing through or adjacent to such land—may be found in the recent case of United States *v.* Winans, 198 U. S., 371. In that case a suit was brought to enjoin the owners of certain lands on the Columbia River from interfering with the exercise by the Indians on the Yakima Indian Reservation in the State of Washington of fishing rights and privileges over, on, and adjacent to lands along the Columbia River, patented to the defendants therein,

which rights were claimed under the provisions of a treaty made in 1859 between the Indians and the United States. This treaty reserved to them the exclusive right to fish in all streams running on and within certain lands within prescribed limits, and to fish in common with the citizens of the territory at all accustomed places in the vicinity, and further secured to such Indians the right of way over all lands necessary for carrying such reserved rights into effect, together with the privilege of erecting on any of the then public lands temporary buildings for the curing of fish. Subsequently the lands between the Columbia River and the special tract set aside and known as their "reservation" were entered by citizens of that State without reservations therein of any kind being issued to them. Grants from the State of Washington to the shore land fronting the patented lands were also procured by the patentees, together with licenses from the State to maintain devices for taking fish, called fish wheels. By virtue of these patents, grants, and right thus acquired by the landowners, it was maintained that they could preclude the Indians from fishing along the shores and from crossing the patented lands for that purpose, in respect to which it was argued that the Indians, under the rights reserved to them and recognized by the Government in the treaty, acquired "merely an executory license or privilege, applying to no certain and defined places, and revocable at will of the United States, to fish, hunt, and build temporary houses upon public lands, in common with white citizens, upon whom the law has conferred no title by occupancy whatever." These contentions were sustained by the United States circuit court in that State (United States *v.* Winans, 73 Fed., 72, 74), Judge Hanford, *inter alia*, observing:

"The theory that lands conveyed by government patents, after being so conveyed and appropriated by individual citizens, still remain subservient to use and occupation by the Indians for travel over the same, otherwise than by lawfully established public highways and for camping grounds, finds no support in the provisions of the treaty, nor in the rules for the construction and interpretation of statutes, which must be applied in the interpretation of the treaty and of the public-land laws of the United States."

But on appeal to the United States Supreme Court this decision was reversed (198 U. S., 381), the court holding in substance that, notwithstanding patents were issued to the lands by the Government, the patentees took the same subject to the rights reserved to the Indians thereafter to fish along the shores of the Columbia River, including a right to erect temporary structures for that purpose, and to retain such easements as would enable the privileges thus reserved to be executed. In discussing the effect of the patents the court say:

"The reservations were in large areas of territory and the negotiations were with the tribe. They reserved rights, however, to every individual Indian, as though named therein. They imposed a servitude upon every piece of land as though described therein. There was an exclusive right of fishing reserved within certain boundaries. There was a right outside of those boundaries reserved 'in common with citizens of the territory.' The land department could grant no exceptions from its provisions. It makes no difference, therefore, that the patents issued by the department are absolute in form. They are subject to the treaty as to the other laws of the land."

It is clear from the foregoing decision (1) that whether the landed proprietor be the Government, a tribe of Indians, or other owner, such proprietor may reserve or grant a right or interest in, over, and appurtenant to or in any manner connected with its lands, not necessarily to an individual alone, but to a class of individuals in general as well as in particular, without limit as to time, application, and use of the rights or privileges thus reserved, dedicated, or

granted; (2) and such right or interest in its public lands becomes effective in favor of those for whom it may be reserved or to whom it may be dedicated, and against those subsequently acquiring title thereto, even though such rights may not be exercised until after the lands shall have been patented to others; (3) and that in so far as the binding effect thereof is concerned upon such subsequent purchaser it is immaterial that such reservations or exceptions are not specified in the patents or other instruments of conveyance.

Reservations of this class are fully and ably discussed by the supreme court of Kentucky in Rowan's Ex'rs. *v.* Town of Portland, 8 B. Monroe, 232. The supreme court of New Hampshire, in the case of State *v.* Franklin Falls Co., 49 N. H., 240, 256, declines either to agree with the reasoning of that court or to follow the rule there enunciated; but the United States Supreme Court, in Morgan *v.* Ry. Co., 96 U. S., 716, clearly adopts the reasoning applied by the Kentucky court and observes that the consideration there given these questions is a full, able, and correct exposition of the law on the subject, with which conclusion we concur. In Rowan's Ex'rs. *v.* Ry. Co., *supra*, the dedication related to certain streets adjacent to a stream and included the right of wharfage or right to land boats and other vessels along that part of the street bordering upon the river. The court, in discussing the legal effect thereof, concludes that the grantor holding title subject to the use to which it was dedicated held the title thereto in himself as trustee for the public, which his grantee took subject to such trust; and further observes:

"Whether the public at large was or could be the immediate grantee or recipient of this right we should consider it fruitless to inquire. The potential right of use in and by the public was created by the sale and conveyance of the lots. And whether it passed at once to the public, or remained in abeyance, or is the mere result of an estoppel, or vested in the purchasers of lots as a part of the estate conveyed to them, it was in either case alike perfect and beyond the future control of the original proprietor or his alienees of the title on which this right of use was engrafted."

Again, as stated in Pearsall *v.* Post, 20 Wendell, 111, 119:

"It seems to be well settled by the Supreme Court of the United States, by several courts in the neighboring States, to which we may, perhaps, add the court of chancery in this State, that dedicatons of land for religious and charitable purposes, as well as for public ways and squares, commons, parks, and other easements in nature of ways, are to be upheld, although there be no person *in esse* capable of taking as a grantee at the time. It was remarked by Mr. Justice Thompson, in Cincinnati *v.* White's Lessee, 6 Peters, 429, 436, that 'the principle, if well founded in law, must have a general application to all appropriations and dedications for public use, where there is no grantee *in esse* to take the fee.' He adds: 'This forms an exception to the rule applicable to private grants and grows out of the necessity of the case.' These remarks comprehend every conceivable case where a man has furnished evidence of a clear intent to give up his real estate for the purposes *of any legitimate public use*."

Privileges of this class were not unusual and were recognized as being subject to dedication, in the early history of the law upon the subject, as disclosed by further remarks therein of the same court, namely:

"I pass over the more usual instances of easements, such as ways, commons, and water privileges, etc., enjoyed either by individuals, towns, or other corporations. * * * We may also pass over those which are less common, and one put by Mr. Justice Thompson, in 6 Peters, 437, from McConnell *v.* Lexington, 12 Wheat., 582, the reservation of a spring of water for public use. It was made to a corporation which might turn the spring to its own or public purposes. Thus, the user was invoked to establish an individual right. A like

case is mentioned in Co. Litt., 56 a, a customary watering place in the Inhabitants of Southwarke, for violating which an action was held to lie."

In the spring case alluded to it appears that the Commonwealth of Virginia in 1773, by an act known as the land law, reserved 640 acres of land, upon which the spring was situated, for the benefit of those who had settled in a village or city, afterwards to be laid out into lots and divided among such settlers. The spring was in common use by the inhabitants of a village located on this tract and [was] afterwards claimed by one of the purported grantees of the lot upon which it was situated. The court, however, in an opinion by Mr. Chief Justice Marshall, held that the use of the spring by the public and the recognition thereof for a long period of time constituted such a dedication; and that even though the claimant thereof be considered the grantee of the land upon which the spring was situated, its use for the purposes mentioned, although no reservation was made in the deed, must be deemed to have been reserved. It may be said that in that case the entire public exercised the right to the use of the spring thus dedicated, but it must be remembered that the exercise of this right was merely by the individuals constituting the public. In the case at bar the public exercises the right in a somewhat similar manner, except on a larger and more extensive scale, in that an appropriation by any individual or corporation gives it a right in and to the flow and use of the water appropriated for the purposes for which it is diverted, which right may afterwards be subject to sale and transfer. But it is clear that if a dedication can be made to the public of a spring or a stream in the manner indicated in the last case quoted, the owner of any source of water supply may make a like dedication in that or in any other manner determined upon. The manner of making the dedication, as well as its legal effect, must be determined from the act or instrument by which it is made. In the case under consideration it will be observed that the language used is that the surplus waters of the streams and of other sources of water supply designated shall *remain and be held* free for the appropriation and use of the public for (1) irrigation, (2) mining, and (3) manufacturing purposes. The manner of appropriating and using the water for irrigation, manufacturing, and mining purposes was at that time and has been at all times since well understood; hence the use by the public and manner thereof is specified, meaning, when interpreted in the light of the then existing facts, the usual manner of applying it for power purposes and of diverting it by means of ditches and other systems in use for irrigation, including also the usual methods in use by miners.

It follows that the rights reserved to the public and dedication of the surplus waters therefor were intended for use in that manner. Construed then with the act of 1866 and other provisions of the act of 1877, we are of the opinion that all lands settled upon after the date of the latter act were accepted with the implied understanding that (except [as] hereinafter stated) the first to appropriate and use the water for the purposes specified in the act should have the superior right thereto.

So far as we are able to determine, the question as here presented has not heretofore been squarely before any of the courts. But, while not deemed essential to an adjudication therein, we find the act of 1877 considered to some extent in the following cases: Williams *v.* Altnow (51 Or.), 95 Pac., 200; Farm Investment Co. *v.* Carpenter, 9 Wyo., 110; United States *v.* Conrad In. Co., 156 Fed., 123, 128; United States *v.* Rio Grande Irr. Co., 174 U. S., 690; Gutierres *v.* Albuquerque Land Co., 188 U. S., 545; Kansas *v.* Colorado, 206 U. S., 46.

In the first case mentioned, Altnow, who was the proprietor of the land upon which Warm Springs Creek had its source, claimed both as a prior appro-

priator and as a riparian owner. To his riparian claim it was maintained as a defense that his lands were settled upon after the date of the desert-land act, for which reason he was not a riparian proprietor in the sense that as such alleged riparian owner he could assert a right in the stream for irrigation; and this contention was in that case expressly upheld by the trial court. On this point Mr. Chief Justice Bean observes that Altnow's claim as riparian proprietor (all other parties therein being in the same position in this respect) could not be upheld for two reasons: (1) That he relied upon his claim as prior appropriator and was bound by it; (2) that the lands having been entered since the year 1877, "it is a serious question whether the desert-land act does not abolish the so-called modified doctrine of riparian rights, which gives to riparian proprietors the right to use water for irrigation as to all lands through which nonnavigable streams flow, the title to which has been acquired from the Government of the United States since the passage of that act." And after quoting from the act, he further remarks:

"The Government of the United States, as the primary owner of the soil, undoubtedly has the right to make such provisions concerning the waters of nonnavigable streams thereon as it deems proper, and it is at least a debatable question whether, by the language quoted, Congress did not intend to recognize and assent to the appropriation of such waters in contravention to the common-law doctrine of riparian rights as to persons subsequently acquiring title from the United States. United States *v.* Rio Grande Irr. Co., 174 U. S., 690."

In Wyoming the doctrine of priority of appropriation for beneficial use in contravention to the common-law rule on the subject prevails. By legislative enactment of 1886 the water of every natural stream in that State was declared to be the property of and dedicated to the use of the public. The manner of appropriation and acquirement of such rights are specified, included among which priority of appropriation for a beneficial use was declared to give the better right. It is thus evident that without the provisions of the desert-land act the court there held and was bound to adhere to that doctrine. But in Farm Investment Co. *v.* Carpenter, 9 Wyo., 110, Mr. Chief Justice Potter, in discussing the question as to whether an express constitutional or statutory declaration was necessary in the first instance to render the streams and other natural bodies of water the property of the public and subject to the control of the laws of the State, without reference to riparian rights, says:

"If any consent of the General Government was primarily requisite to the inception of the rule of prior appropriation, that consent is to be found in several enactments by Congress, beginning with the act of July 26, 1866, and including the desert-land act of March 3, 1877. Those acts have been too often quoted and are too well understood to require a restatement at this time at the expense of unduly extending this opinion."

In New Mexico Territory, where the doctrine of prior appropriation also prevails, a similar question to that in the Wyoming case came before the court in Gutierres *v.* Albuquerque Land Co., 188 U. S., 545. The question there involved the validity of a territorial act permitting the construction of canals and condemning rights of way, etc., in reference to which it was urged that the territorial act was invalid because it not only assumed to dispose of the property of the United States without its consent but was in conflict with the legislation of Congress and therefore void. It was there argued that the waters affected by the statute were public and exclusively the property of the United States; but the statute alluded to permitted private parties and corporations to acquire the unappropriated waters in violation of the right of the Government to control and dispose of its property wherever situated. In con-

sidering this feature, Mr. Justice White, speaking for the court, at page 552 of the opinion, observes:

"Assuming that the appellants are entitled to urge the objection referred to, we think, in view of the legislation of Congress on the subject of the appropriation of water on the public domain, particularly referred to in the opinion of this court in United States *v.* Rio Grande Irrigation Co., 174 U. S., 690, 704–706, the objection is devoid of merit. * * * By the act of March 3, 1877, c. 107, 19 Stat., 377, the right to appropriate such an amount of water as might be necessarily used for the purpose of irrigation and reclamation of desert land, part of the public domain, was granted, and it was further provided that 'all surplus water over and above such actual appropriation and use, together with the water of all lakes, rivers, and other sources of water supply upon the public lands and not navigable, shall remain and be held free for the appropriation and use of the public for irrigation, mining, and manufacturing purposes, subject to existing rights.'"

In United States *v.* Rio Grande Irr. Co., the inquiry was as to the navigability of the Rio Grande River and to the effect a proposed dam therein would have on navigation. While it was there unquestioned that the common-law rule was that every riparian owner was entitled to the continual flow of the stream and that States and Territories had the power to change this rule and to permit the appropriation of the flowing waters for such purposes as they deemed wise, the court states that this power "is limited by the superior power of the General Government to secure the uninterrupted navigation of all streams within the limits of the United States." It was urged in this connection that the desert-land act of 1877 also included therein the right to appropriate the waters of any stream, even though the depletion caused thereby should impede navigation. In the opinion the desert-land act, together with that of the acts of 1866 and 1891, are referred to, concerning which the court, by Mr. Justice Brewer, at page 706, comments as follows:

"Obviously by these acts, so far as they extended, Congress recognized and assented to the appropriation of water in contravention of the common-law rule as to continuous flow. To infer therefrom that Congress intended to release its control over the navigable streams of the country and to grant in aid of mining industries and the reclamation of arid lands the right to appropriate the waters on the sources of navigable streams to such an extent as to destroy their navigability is to carry those statutes beyond what their fair import permits. This legislation must be interpreted in the light of existing facts—that all through this mining region in the West were streams, not navigable, whose waters could safely be appropriated for mining and agricultural industries, without serious interference with the navigability of the rivers into which those waters flow. And in reference to all these cases of purely local interest, the obvious purpose of Congress was to give its assent, so far as the public lands were concerned, to any system, although in contravention to the common-law rule, which permitted the appropriation of those waters for legitimate industries."

These appear to be the only cases in which the attention of the court has been called to this act, the plain inference from which is that in the opinion of the eminent jurists quoted, the act of March 3, 1877, was such a reservation by the National Government to and for the public and such dedication thereto of all its rights in and to all the waters flowing through its public lands for irrigation, manufacturing, and mining purposes, as to abrogate the modified common-law rules upon the subject, in so far as applicable to all lands entered after that date.

But the effect of the language of the act that "there shall remain and be held free for the appropriation and use of the public for irrigation," etc., we think, while constituting words of reservation and dedication, limits the rights thereunder to the deprivation of the riparian lands of the water, only, in so far as it may be claimed by the riparians for the purposes there enumerated. One of the rights inseparable from the land has always been that the owner of such land was entitled to an adequate supply of water flowing over it for domestic use, together with sufficient for the domestic animals necessary for the proper subsistence and maintenance of the landed proprietor and his family. This necessary use, no doubt, gave rise to the doctrine of riparian rights in the earliest development of the law upon the subject, followed by requirements for navigation, next extended to include the right to its use for power purposes, and later to the production of such garden and grains as were essential to the subsistence of the family of such riparian owner. At first the right of all riparians was evidently restricted to the demands upon the stream for the first purposes named. Lastly, as civilization progressed and extended over the semiarid sections throughout the different nations, the riparian demands accordingly became more extensive and enlarged to include irrigation, but limited at first, no doubt, to the watering of such garden and other produce reasonably necessary for the riparians' domestic consumption, and as the strictly arid localities became populated, by reason of the correspondingly increased commercial, agricultural, and mining development, this right was finally extended to include the irrigation, not only for the limited purposes mentioned, but to the watering of large areas in the production of grains and other agricultural products, together with its expansion thereof to include all its present uses.

The language used in this act was clearly intended to change the rule respecting the right of riparians to the use of water for irrigation, mining, and power purposes; but as in the last case cited it has its limits. It does not go so far as to affect the rights originally giving rise to the doctrine of riparian rights, that is, for domestic use, including the watering of domestic animals and such stock as may be essential to the sustenance of the owners of lands adjacent to the streams or other bodies of water. And as held in the last case cited, although abrogating the common-law rule on the subject, the act was not intended to permit appropriators to deplete the flow to such an extent as materially to impair the navigation of the rivers to which such streams directly or indirectly may be tributaries. The reason for this is plain; to permit an interference with navigation would be to deprive the entire public of a valuable right which at all times has been recognized as paramount to that of the individual desiring such interference; while to permit an appropriation of water depriving the owner of the land through which it may flow of its use for irrigation affects such person only. So far as the Government may be concerned by the depletion of a particular tract of land of such benefit, if any, it is recouped by the reclamation of a like tract for which the diversion causing the injury may be made.

However, it can not be presumed that it was the intention of Congress to render the soil absolutely worthless by drying the lands by diversion of the waters flowing through them to nonriparian lands as to leave the soil without the water essential to the owner's domestic needs. Presumably the best possible results for all concerned were intended, which it is clear could best be obtained by permitting the settler to retain the quantity of water essential to the sustenance of his family and to other natural wants incident thereto, but if he does not see proper to apply it to any of the uses specified in the act, then to permit the first home builder on other lands to make such use of it as will

bring into cultivation the lands not adjacent to the streams, thereby protecting the settlers upon both classes of lands, and at the same time not only encourage home building but enable the Government to dispose of more of its lands, and to enhance its revenues proportionately.

It often happens that an owner of land in arid districts does not want to farm them, but merely wants a home where he may raise stock or engage in other pursuits, requiring only sufficient water supply to meet the natural wants incident thereto, and for which no artificial diversion or application of the stream may become necessary. It will not, therefore, necessarily be presumed that such settler intends to irrigate his lands or that he will ever demand the water for such purposes, for which reason Congress evidently intended by the language used in the act of 1877 that if desired for such purposes some manifestation thereof, by diversion or other sufficient notice, should be given, and if not desired for the reclamation of his lands that the owner should not be permitted to complain if another shall so apply it.

But, as regards the requirements for domestic use, the settlement, or other steps taken looking toward the procurement of title thereto, gives ample notice that the water for all necessary domestic uses is and will continue to be demanded as appurtenant to the land entered—as much so as would a diversion of the water for such purposes; while if intended to be appropriated for mining, irrigation, or power purposes, some affirmative action in that direction is essential, and it is but reasonable to require a clear manifestation of an intent or notice thereof. This requirement is vital to the initiation of such a right, for the same reason that some notice is exacted for the entry of the land itself. Congress could reasonably presume that if an appropriation were desired for the purpose mentioned in the act, some steps would be taken manifesting such intent, and that if the owner is not the first to move in that direction the person making an application thereof to a beneficial use within a reasonable time ought to be rewarded for his diligence, and he is entitled to have his rights in that respect recognized and protected. For this reason the settler who has acquired title to the land through which any stream may flow took it subject to the rights of the person who has or who may subsequently make the first use of such stream for the purpose enumerated in the act, excepting only as to the natural wants and needs of such settler.

Our attention is called to references in our statute to riparian rights (B. and C. Comp., 4994, 5000), which, it is argued, recognizes the doctrine of riparian rights as being in force in this State, regardless of the act of Congress under consideration. It could with equal strength be maintained that sec. 5002 *ib.*, which provides that "all controversies respecting rights to water under this act shall be determined by the dates of the appropriations as respectively made by the parties," constitutes a declaration to the effect that the doctrine of prior appropriation shall prevail.

The statute does not attempt to define riparian rights nor to determine the extent or effect of the doctrine as applied to irrigation. It has reference only to such rights as such riparian owner as the proprietor may have, whatever they may be; and the question as to what such rights are, and since 1877 have been, is the one under consideration here. Owners of land adjacent to bodies of water have riparian rights other than those presented in this controversy: See Morton *v.* O. S. L. Ry. Co., 48 Or., 444; Coquille Mill and M. Co. *v.* Johnson (Or.), 98 Pac., 154. As hereinbefore held, the act of 1877 only affects riparian rights to lands the title to which has been acquired since that date, and then only in so far as a claim to the use of water may be asserted, as riparian owner for the purposes in the act enumerated. And in this connection it will be observed that sec. 5000, B. and C. Comp., protects the owner contiguous to

the stream, as against those claiming under the act of which that section is a part, in his right to the flow of the stream to the extent required for household, domestic, and other uses incident thereto, with sufficient quantity for irrigation purposes to the extent then actually needed and in use. An exception to that extent is accordingly made in favor of the landowner, as against, and only to the extent of, such rights as may be asserted under the act.

Our attention is called to Sturr *v.* Beck, 133 U. S., 541. That was a controversy between a riparian owner and a subsequent but prior appropriator, and was submitted on an agreed statement of facts. Based upon these stipulations, the trial court made findings, among which was that the defendant's first settlement upon his land through which the stream flowed was in March, 1877, and that he made a homestead filing thereon on the 25th of the same month. Those findings were conclusive upon the appellate court. The date alluded to does not disclose whether the settlement was prior or subsequent to March 3, 1877, the date of the desert-land act.

Owing, therefore, to the uncertainty as to the date of settlement this decision can not be held in point. And the further fact that no reference appears as to the exact date clearly indicates that either the settlement was made before that date, or that the question did not occur to the litigants and was accordingly not urged before the court, nor considered by it. But whatever view may be taken in this respect, its bearing on the question at hand is practically disregarded, if not overruled, by that court in its declaration on the subject through Mr. Justice Brewer, in United States *v.* Rio Grande Irr. Co., above quoted, as well as in the general reference to this act by the same court in an opinion by Mr. Justice White in Gutierres *v.* Albuquerque Land Co., 188 U. S., 545. To the extent, therefore, that Sturr *v.* Beck may be deemed a precedent, as regards riparian rights, its weight is materially lessened, if indeed the rule as there and previously enunciated on the subject is not overruled by that court in the recent case of Kansas *v.* Colorado, 206 U. S., 40. In Sturr *v.* Beck it was, in effect, held that the plaintiff could make no appropriation as against Beck, who was a riparian proprietor and who was entitled to the undiminished flow of the stream. This claim as to the law was asserted and the same application thereof insisted upon in Kansas *v.* Colorado, in which the citizens of Kansas insisted that large quantities of water were being diverted from the Arkansas River by the inhabitants of Colorado, a large number of whom were claiming as prior appropriators and diverting the water to nonriparian lands, as against Kansas, a riparian proprietor. In Kansas the modified doctrine of riparian rights prevailed, while in Colorado prior appropriation was and is recognized as the governing doctrine. The court refused injunctive relief and dismissed the bill, stating in substance that if the riparian doctrine should prevail in Kansas as against Colorado and against the nonriparian users whose rights were involved therein, Oklahoma and its citizens lower on the Arkansas River might invoke the same rule in opposition to both the citizens of Kansas and Colorado, to their great injury, which doctrine, it is observed, would be ruinous in its effect. The court, in dismissing the bill, indicated that no injunction would lie until a more substantial injury could be shown, and at the same time found that the interference by a large number of the appropriators above in the State of Colorado materially depleted the flow to the riparian lands of the plaintiff. This opinion was written by Mr. Justice Brewer, who was not a member of the court when the case of Sturr *v.* Beck was argued and submitted, for which reason, although a member of the court when the opinion in the latter case was filed, he took no part in the decision. The opinion in the Kansas-Colorado case not only brushes aside the rule claimed to have been announced in Sturr *v.* Beck, regarding riparian rights, but discloses what, in the opinion of the writer, is a strong and

commendable tendency on the part of that great court to recognize that the rigid rules of common law, as interpreted and sought to be applied by those insisting upon the "undiminished flow" theory, are inapplicable to the many new and intricate questions necessarily arising under our form of government and through the arid and semiarid sections. For a specified statement of the facts in this case, disclosing many of the defendants to have been using the water on nonriparian lands, see the first opinion, which was on demurrer: Kansas *v.* Colorado, 185 U. S., 125.

WATER POWERS ON NAVIGABLE STREAMS.

Under existing laws and interpretations thereof the Federal Government is prevented from exercising full sovereign control over any waters except those in the Territories. It will therefore be of interest to review the character of national legislation respecting the development of water powers.

It is clear that on navigable streams the unregulated development of water power would interfere with navigation. Therefore, while the authority of the Federal Government does not extend to the regulation of water-power development per se, it must intervene to the extent necessary to preserve or to facilitate navigation. Power development on these streams must therefore be subject to the dictates of the Federal Government in so far as may be necessary to accomplish this purpose. The present national law relative to the development of water powers on navigable streams reads as follows (Rev. Stat., chap. 3508, vol. 34, p. 386):

An act to regulate the construction of dams across navigable waters.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That when, hereafter, authority is granted by Congress to any persons to construct and maintain a dam for water power or other purposes across any of the navigable waters of the United States, such dams [*sic*] shall not be built or commenced until the plans and specifications for its construction, together with such drawings of the proposed construction and such map of the proposed location as may be required for a full understanding of the subject, have been submitted to the Secretary of War and Chief of Engineers for their approval, or until they shall have approved such plans and specifications and the location of such dam and accessory works; and when the plans for any dam to be constructed under the provisions of this act have been approved by the Chief of Engineers and by the Secretary of War it shall not be lawful to deviate from such plans either before or after completion of the structure unless the modification of such plans has previously been submitted to and received the approval of the Chief of Engineers and of the Secretary of War: *Provided*, That in approving said plans and location such conditions and stipulations may be imposed as the Chief of Engineers and the Secretary of War may deem necessary to protect the present and future interests of the United States, which may include the condition that such persons shall construct, maintain, and operate, without expense to the United States, in connection with said dam and appurtenant works, a lock or locks, booms, sluices, or any other structures which the Secretary of War and the Chief of Engineers at any time may deem necessary in the interest of navigation, in accordance

with such plans as they may approve, and also that whenever Congress shall authorize the construction of a lock, or other structures for navigation purposes, in connection with such dam, the person owning such dam shall convey to the United States, free of cost, title to such land as may be required for such constructions and approaches, and shall grant to the United States a free use of water power for building and operating such constructions.

SEC. 2. That the right is hereby reserved to the United States to construct, maintain, and operate, in connection with any dam built under the provisions of this act, a suitable lock or locks, or any other structures for navigation purposes, and at all times to control the said dam and the level of the pool caused by said dam to such an extent as may be necessary to provide proper facilities for navigation.

SEC. 3. That the person, company, or corporation building, maintaining, or operating any dam and appurtenant works, under the provisions of this act, shall be liable for any damage that may be inflicted thereby upon private property, either by overflow or otherwise. The persons owning or operating any such dam shall maintain, at their own expense, such lights and other signals thereon and such fishways as the Secretary of Commerce and Labor shall prescribe.

SEC. 4. That all rights acquired under this act shall cease and be determined if the person, company, or corporation acquiring such rights shall, at any time, fail to comply with any of the provisions and requirements of the act, or with any of the stipulations and conditions that may be prescribed as aforesaid by the Chief of Engineers and the Secretary of War.

SEC. 5. That any persons who shall fail or refuse to comply with the lawful order of the Secretary of War and the Chief of Engineers, made in accordance with the provisions of this act, shall be deemed guilty of a violation of this act, and any persons who shall be guilty of a violation of this act shall be deemed guilty of a misdemeanor, and on conviction thereof shall be punished by a fine not exceeding five thousand dollars, and every month such person shall remain in default shall be deemed a new offense and subject such persons to additional penalties therefor; and in addition to the penalties above described the Secretary of War and the Chief of Engineers may, upon refusal of the persons owning or controlling any such dam and accessory works to comply with any lawful order issued by the Secretary of War or Chief of Engineers in regard thereto, cause the removal of such dam and accessory works as an obstruction to navigation at the expense of the persons owning or controlling such dam, and suit for such expense may be brought in the name of the United States against such persons, and recovery had for such expense in any court of competent jurisdiction; and the removal of any structures erected or maintained in violation of the provisions of this act or the order or direction of the Secretary of War or Chief of Engineers made in pursuance thereof may be enforced by injunction, mandamus, or other summary process, upon application to the circuit court in the district in which such structure may, in whole or in part, exist, and proper proceedings to this end may be instituted under the direction of the Attorney-General of the United States at the request of the Chief of Engineers or the Secretary of War; and in case of any litigation arising from any obstruction or alleged obstruction to navigation created by the construction of any dam under this act, the cause or question arising may be tried before the circuit court of the United States in any district in which any portion of said obstruction or dam touches.

SEC. 6. That whenever Congress shall hereafter by law authorize the construction of any dam across any of the navigable waters of the United States, and no time for the commencement and completion of such dam is named in

said act, the authority thereby granted shall cease and be null and void unless the actual construction of the dam authorized in such act be commenced within one year and completed within three years from the date of the passage of such act.

SEC. 7. That the right to alter, amend, or repeal this act is hereby expressly reserved as to any and all dams which may be constructed in accordance with the provisions of this act, and the United States shall incur no liability for the alteration, amendment, or repeal thereof to the owner or owners or any other persons interested in any dam which shall have been constructed in accordance with its provisions.

SEC. 8. That the word "persons" as used in this act shall be construed to import both the singular and the plural, as the case demands, and shall include corporations, companies, and associations.

Approved, June 21, 1906.

The above-quoted act vests no authority in the Federal Government to regulate corporate features of any development, nor the distribution of power, nor the rates to be charged therefor, nor any other matter of public interest except that of navigation. In pursuance of the law, seventy-eight special acts have been passed by Congress authorizing the construction of dams across navigable waters. Whether or not the authority indicated in the act confers upon the Federal Government the right to do more than to preserve the navigability of an inland waterway is a question that is in dispute at the present time. President Roosevelt vetoed two bills granting franchise for the construction of dams under this act, declaring that he would withhold his approval from all bills of this kind unless they provided that—

> There should be a license fee or charge, which, though small or nominal at the outset, can in the future be adjusted so as to secure a control in the interest of the public.

The following excerpt from a report[a] presented by Hon. Knute Nelson, United States Senator from Minnesota, on behalf of the Senate Committee on Commerce, contains an argument against such a doctrine:

> The President, in a communication addressed to the chairman of the Senate Committee on Commerce, dated March 18 last, as well as in his veto message of April 17, relating to the bill (H. R. 15444) to extend the time for the construction of a dam across Rainy River, has declared it to be his policy not to approve of any bill permitting the construction of a dam by private parties across a navigable stream, although due provision is made for the conservation of the stream for the purposes of navigation, unless the bill provides for the payment of a royalty or compensation to the United States for the use of the water of the stream for purposes other than navigation.
>
> This is a new departure from the policy heretofore pursued in respect to legislation authorizing the construction of such dams, and in view of this fact it becomes important to inquire whether the Government of the United States has the right to require compensation for the use of water in such streams for purposes other than navigation.

[a] S. Rept. No. 585, Sixtieth Cong., 1st sess., pp. 3–9.

The common-law doctrine of England that a stream is not deemed to be a navigable watercourse unless the tide ebbs and flows in it is not the law in this country. The question whether a watercourse is a navigable stream is one of fact. If it is capable of being used for the purposes of trade and commerce in any mode, even for floating rafts of logs and timber, it is deemed to be a navigable stream.

(The Montello, 20 Wall., 430.)

(St. Anthony Water Power Company *v.* St. Paul Water Commissioners, 168 U. S., 349.)

The title to the water of a navigable stream within the borders of a State is not in the Federal Government, but in the State; and title to the banks and bed of the stream, after the Federal Government has parted with its riparian lands, is either in the State or in the riparian owner, or both, according to the laws of the respective States. These principles have been laid down and applied by the Supreme Court of the United States in the following among other cases, and is the settled law of the land, to wit: Martin *v.* Waddell (16 Pet., 367); Pollard *v.* Hagan (3 How., 212); Goodtitle *v.* Kibbe (9 How., 471); Barney *v.* Keokuk (94 U. S., 324); St. Louis *v.* Myers (113 U. S., 566); Packer *v.* Bird (137 U. S., 661); Hadrin *v.* Jordan (140 U. S., 371); Kaukauna Water Power Company *v.* Green Bay and Mississippi Canal Company (142 U. S., 254); Shively *v.* Bowlby (152 U. S., 1); Water Power Company *v.* Water Commissioners (168 U. S., 349); Kean *v.* Calumet Canal Company (190 U. S., 452); United States *v.* The Chandler Dunbar Water Power Company (U. S. Supreme Court, April 20, 1908).

The use of water in such a stream is a matter of state regulation and state control. In many of the States the common-law rule, as defined in the following language of Chancellor Kent, prevails, to wit:

"Every proprietor of lands on the banks of a river has naturally an equal right to the use of the water which flows in the stream adjacent to his lands, as it was wont to run (currere solebat), without diminution or alteration. No proprietor has a right to use the water to the prejudice of other proprietors above or below him unless he has a prior right to divert it, or a title to some exclusive enjoyment. He has no property in the water itself, but a simple usufruct while it passes along. Aqua currit et debet currere ut currere solebat is the language of the law. Though he may use the water while it runs over his land as an incident to the land, he can not unreasonably detain it or give it another direction, and he must return it to its ordinary channel when it leaves his estate."

In the mining and arid States the rule of prior appropriation for mining and irrigation purposes prevails, and this rule of the States has been recognized by federal statutes (Rev. Stat., secs. 2339–2340). In some of the States there is a mixed application, as in California, of the common-law rule and the rule of prior appropriation.

But whatever rule may prevail in any State as to the use of the water in a stream, it is always subject to the following limitations, laid down by the Supreme Court in the case of the United States *v.* Rio Grande Dam and Irrigation Company (174 U. S., 690):

"Although this power of changing the common-law rule as to streams within its dominion undoubtedly belongs to each State, yet two limitations must be recognized: First, that in the absence of specific authority from Congress a State can not by its legislation destroy the right of the United States, as the owner of lands bordering on a stream, to the continued flow of its water; so far at least as may be necessary for the beneficial uses of the government property. Second, that it is limited by the superior power of the General Government to

secure the uninterrupted navigability of all navigable streams within the limits of the United States. In other words, the jurisdiction of the General Government over interstate commerce and its natural highways vests in that Government the right to take all needed measures to preserve the navigability of the navigable watercourses of the country even against any state action."

Where the Federal Government is not interested as the owner of riparian lands the only interest it has in the water of a stream is as to its use for purposes of navigation, and it can lay no claim to the use of the water for any other purpose, not even for irrigation. (Kansas *v.* Colorado, 206 U. S., 46.)

In this case the United States appeared as intervener, but inasmuch as it founded its claim not on the question of navigation but on the question of irrigation, the court held that it had no ground for intervention and dismissed its petition. In reference to this subject the court says:

"It follows from this that if in the present case the National Government was asserting, as against either Kansas or Colorado, that the appropriation for the purpose of irrigation of the waters of the Arkansas was affecting the navigability of the stream, it would become our duty to determine the truth of the charge. But the Government makes no such contention. On the contrary, it distinctly asserts that the Arkansas River is not now and never was practically navigable beyond Fort Gibson, in the Indian Territory, and nowhere claims that any appropriation of the waters by Kansas or Colorado affects its navigability.

"It rested its petition of intervention upon its alleged duty of legislating for the reclamation of arid lands. * * *

"Turning to the enumeration of the powers granted to Congress by the eighth section of the first article of the Constitution, it is enough to say that no one of them by any implication refers to the reclamation of arid lands. * * *

"While arid lands are to be found mainly if not only in the Western and newer States, yet the powers of the National Government within the limits of those States are the same (no greater and no less) than those within the limits of the original thirteen, and it would be strange if, in the absence of a definite grant of power, the National Government could enter the territory of the States along the Atlantic and legislate in respect to improving, by irrigation or otherwise, the lands within their borders. Nor do we understand that hitherto Congress has acted in disregard to this limitation."

It was the doctrine at common law that a grant of land upon the borders of a navigable stream carried the grant only to high-water mark, while a grant of land bordering upon a nonnavigable stream carried the ownership to the center or thread of the stream, subject to the public easement.

In the case of Hardin *v.* Jordan (140 U. S., 384), the Supreme Court states:

"The United States have not repealed the common law as to the interpretation of their own grants, nor explained what interpretation or limitation should be given to or imposed upon the terms of the ordinary conveyances which they use except in a few special instances; but these are left to the principles of law and rules adopted by each local government where the land may lie. We have adopted the common law, and must therefore apply its principles to the interpretation of their grant."

Further on the court states the same principle in this form:

"In our judgment the grants of the Government for lands bounded on streams and other waters without any reservation or limitation of terms are to be construed as to their effect according to the laws of the State in which the lands lie."

The rule of riparian ownership as to grants of land bordering on a navigable stream is diverse in the various States. Some States hold that the grant

extends only to high-water mark; other States hold that it extends to low-water mark, while another class of States—and perhaps the most numerous—hold that the grant extends to the middle of the stream, subject to the public easement in the water of the stream. But whatever may be the law in this respect as to the effect of the grant, it only relates to the proprietorship in the banks and bed of the stream and not to the ownership of the water in the stream.

In those States which hold that the title of the riparian owner only extends to the high or low water mark the title to the bed of the stream is deemed to be in the State, and whether the title to the bed of the stream is in the riparian owner or in the State, in either case the general title to the water of the stream is deemed to be in the State, but it holds it not absolutely but in trust for all lawful public uses. The State's interest in such a stream is akin to that of a riparian owner, though more comprehensive and general in its nature, and does not exist in hostility to or in diminution of the rights of the riparian owner.

(Rossmiller *v.* State, 114 Wis., 169.)

(Peoples Ice Co. *v.* Davenport, 149 Mass., 322.)

(Brown *v.* Cunningham, 82 Iowa, 512.)

(Braston *v.* Rockport Ice Co., 77 Maine, 100.)

(Martin et al. *v.* Waddell, 16 Peters, 367.)

From the foregoing it will appear that there are three different parties who are interested in the waters of a navigable stream—(1) the United States; (2) the State in which the stream is located; (3) the riparian owner. The interest of the United States is derived from and rests upon that paragraph of the Constitution which gives Congress the power to regulate interstate commerce, and this power only extends to the extent of conserving the navigability of the stream. Beyond that the Federal Government has no interest or property in the stream.

The interest of the State in the stream is derived from its sovereignty and it holds its property in the stream in trust for all public uses but in subrogation to the rights of the Federal Government as to navigation and of the riparian owner. The right to the use of the waters of a stream for any lawful purpose, outside of the right of navigation, belongs wholly to the State and the riparian owner.

(Martin et al. *v.* Waddell, 16 Peters, 367.)

Chief Justice Shaw, in the case of Elliott *v.* Fitchburg Railroad Company (10 Cushing, 191), describes the rights of the riparian owner in the use of water in a stream in the following language, which states the enlarged and modified common-law doctrine:

"The right to flowing water is now well settled to be a right incident to property in the land; it is a right publici juris, of such a character that, while it is common and equal to all through whose land it runs and no one can obstruct or divert it, yet, as one of the beneficial gifts of Providence, each proprietor has a right to a just and reasonable use of it as it passes through his land; and, so long as it is not wholly obstructed or diverted or no larger appropriation of the water running through it is made than a just and reasonable use, it can not be said to be wrongful or injurious to a proprietor lower down. What is such a just and reasonable use may often be a difficult question, depending upon various circumstances. To take a quantity of water from a large running stream for agricultural or manufacturing purposes would cause no sensible or practicable diminution of the benefit, to the prejudice of a lower proprietor; whereas, taking the same quantity from a small running brook passing through many farms would be of great and manifest injury to those below, who need it for domestic supply or watering cattle; and therefore it

would be an unreasonable use of the water, and an action would lie in the latter case and not in the former. It is therefore to a considerable extent a question of degree; still the rule is the same, that each proprietor has a right to a reasonable use of it, for his own benefit, for domestic use, and for manufacturing and agricultural purposes. * * *

"That a portion of the water of a stream may be used for the purpose of irrigating land we think is well established as one of the rights of the proprietors of the soil along or through which it passes. Yet a proprietor can not, under color of that right or for the actual purpose of irrigating his own land, wholly abstract or divert the watercourse or take such an unreasonable quantity of water or make such unreasonable use of it as to deprive other proprietors of the substantial benefits which they might derive from it if not diverted or used unreasonably. * * *

"This rule, that no riparian proprietor can wholly abstract or divert a watercourse, by which it would cease to be a running stream, or use it unreasonably in its passage and thereby deprive a lower proprietor of a quality of his property, deemed in law incidental and beneficial, necessarily flows from the principle that the right to the reasonable and beneficial use of a running stream is common to all the riparian proprietors, and so each is bound to use his common right as not essentially to prevent or interfere with an equally beneficial enjoyment of the common right by all the proprietors. * * *

"The right to the use of flowing water is publici juris, and common to all the riparian proprietors; it is not an absolute and exclusive right to all the water flowing past their land, so that any obstruction would give a cause of action; but it is a right to the flow and enjoyment of the water, subject to a similar right in all the proprietors to the reasonable enjoyment of the same gift of Providence. It is therefore only for an abstraction and deprivation of this common benefit or for an unreasonable and unauthorized use of it that an action will lie."

The doctrine of prior appropriation, already referred to, is thus described by Justice Field in the case of Jennison *v.* Kirk (98 U. S., 453). After describing the system of discovery and appropriation and development of mining claims, he adds the following:

"But the mines could not be worked without water. Without water the gold would remain forever buried in the earth or rock. To carry water to mining localities when they were not on the bank of a stream or lake became therefore an important and necessary business in carrying on mining. Here, also, the first appropriator of water to be conveyed to such locality for mining or other beneficial purposes was recognized as having, to the extent of actual use, the better right. The doctrine of the common law respecting the right of riparian owners was not considered as applicable, or only in a very limited degree, to the conditions of miners in the mountains. The waters of rivers and lakes were, consequently, carried great distances in ditches and flumes, constructed with vast labor and enormous expenditures of money, along the sides of mountains and through canyons and ravines, to supply communities engaged in mining as well as for agriculturists and ordinary consumption. Numerous regulations were adopted, or assumed to exist from their obvious justness, for the security of these ditches and flumes, and for the protection of rights to water, not only between different appropriators, but between them and the holders of mining claims. These regulations and customs were appealed to in controversies in the state courts, and received their sanction; and properties to the value of many millions rested upon them. For eighteen years, from 1848 to 1866, the regulations and customs of miners, as enforced and molded by the courts and sanctioned by the legislation of the State, consti-

tuted the law governing property in mines and in water on the public mineral lands."

These water rights, by prior appropriation, as described by Justice Field, were recognized and confirmed by congressional legislation in 1866 and in 1870. Those acts are now sections 2339 and 2340 of the Revised Statutes. Justice Field further adds:

"It will thus be seen that the federal statutes merely gave a formal sanction to the rules already established. Those rules had been built up in reliance on the tacit acquiescence of the United States, the true owner of the lands and waters on which appropriations were made, and these statutes acquiesced therein expressly, 'a voluntary recognition of the preexisting right rather than the establishment of a new one.'"

In the case of Broder *v.* Natoma Water Company (101 U. S., 274) the Supreme Court, in referring to the contention that these statutes established a new right, uses the following language:

"We are of the opinion that it is the established doctrine of this court that rights of miners who had taken possession of mines and worked and developed them, and the rights of persons who had constructed canals and ditches to be used in mining operations and for purposes of agricultural irrigation, in the region where such artificial use of the water was an absolute necessity, are rights which the Government had, by its conduct, recognized and encouraged and was bound to protect before the passage of the act of 1866, and that the section of the act which we have quoted was rather a voluntary recognition of a preexisting right of possession, constituting a valid claim to its continued use, than the establishment of a new one."

These decisions of Judge Shaw, of Massachusetts, and of Justice Field, of the Supreme Court, describe fully the rights of the riparian owners to the use of the water both under the doctrine of the common law and under the so-called doctrine of prior appropriation, and the case of Rossmiller *v.* The State (114 Wis., 169), and the cases therein referred to, as well as the case of Martin et al. *v.* Waddell (16 Peters, 367), show the interest and property of a State in the waters of a stream.

From the foregoing statement and citation of authorities it is evident that the only use of the waters of a stream in which the United States has any property is its use for purposes of navigation. In the use of the stream for any other purpose the Federal Government has no property, and hence has nothing to sell or to exact compensation for.

The plan proposed by the President would deprive the States and the riparian owners of their rights in the use of the water of a navigable stream now vested in them by law, and would concentrate the entire disposal and control in the Federal Government, a power which neither the States nor the riparian owners can, with justice or safety, for a moment concede. But, assuming for the sake of the argument that the Federal Government can lay a tribute in such cases as is proposed by the President, it can not be under the interstate-commerce clause of the Constitution, but must be under section 8 of article 1, which reads as follows:

"SEC. 8. The Congress shall have power to lay and collect taxes, duties, imposts, and excises, to pay the debts and provide for the common defense and general welfare of the United States; but all duties, imposts, and excises shall be uniform throughout the United States."

Such a tribute must be either a direct tax or in the nature of an impost or excise tax. If a direct tax, it can not be levied directly by the Federal Government, but must be apportioned among the States, leaving each State to make the collection; and if an impost or excise tax, then it must be levied by the rule

of uniformity upon every dam and water power in the United States not constructed directly or indirectly by the Federal Government. In other words, there must be a general excise law on the subject. The power of the Federal Government over the navigable streams of the country is no greater in the so-called Western or public-land States than in the New England States. If a tribute can be levied on a dam and water power in Minnesota or Colorado, it can be levied on a dam and water power in Maine or Massachusetts, for the power of the Federal Government over navigable streams is the same in the one case as in the other. In the case of Pollock *v.* Farmers Loan and Trust Company (157 U. S., 557) the court states:

"Thus in the matter of taxation the Constitution recognizes the two great classes of direct and indirect taxes, and lays down two rules by which their imposition must be governed, namely, the rule of apportionment as to direct taxes and the rule of uniformity as to duties, imposts, and excises."

In the case of Thomas *v.* United States (192 U. S., 363), Chief Justice Fuller says:

"And these two classes, taxes so called, and 'duties, imposts, and excises,' apparently embrace all forms of taxation contemplated by the Constitution. As was observed in Pollock *v.* Farmers Loan and Trust Company (157 U. S., 429, 557), 'Although there have been from time to time intimations that there might be some tax which was not a direct tax nor included under the words "duties, imposts, and excises," such a tax for more than one hundred years of national existence has as yet remained undiscovered, notwithstanding the stress of particular circumstances has invited thorough investigation into sources of revenue.' * * *

"There is no occasion to attempt to confine the words duties, imposts, and excises to the limits of precise definition. We think that they were used comprehensively to cover customs and excise duties imposed on importation, consumption, manufacture, and sale of certain commodities, privileges, particular business transactions, vocations, occupations, and the like."

An act authorizing the construction of a dam is, so far as the United States is concerned, a mere revocable license or privilege, and if a tax can be imposed on such a privilege it must be general and uniform throughout the United States. It must apply to all dams and water powers on navigable streams throughout the entire country.

Nearly all navigable streams in their upper and more remote courses are not, as a matter of fact, navigable, and in such reaches of the river dams can be erected and water powers created under state authority and state license, and so long as such dams and water powers do not materially injure or diminish the navigability of the stream in its navigable portions the Federal Government has no ground for interference. It has been customary, however, in many of such cases to apply to Congress for a federal license, and the granting of it, while not necessary, serves a twofold purpose, first, that it authorizes the Federal Government, through the War Department, to control and direct the construction of the dam, and, second, that it recognizes the fact, which might otherwise require proof, that the dam will not affect the navigability of the stream in its navigable portions.

(Kansas *v.* Colorado, 206 U. S., 46.)

(United States *v.* Rio Grande Company, 174 U. S., 690.)

And in such cases it is of as much advantage to the United States as to the grantee of the license to have congressional action and recognition, but in such cases the Federal Government has nothing to sell, and, therefore, has no moral or legal ground to demand compensation in any form.

An adverse comment on the above report, made as a private memorandum on May 11, 1908, by Morris Bien, supervising engineer in charge of land and legal matters, United States Reclamation Service, is presented below:

MAY 11, 1908.

Memorandum upon report of Committee on Commerce of Senate to accompany H. R. 14707, Sixtieth Congress, first session, Senate Report 585.

The report discusses the power of Congress to authorize charges for the use of waters of navigable streams for power and other purposes in connection with dams authorized to be constructed across such streams. A number of decisions are cited tending to show that the ownership of the waters of navigable streams is in the States. In many of the decisions cited the particular point of ownership is not necessary to the decision of the case and the expressions quoted are from the general discussion of the subject.

A careful study of the cases will lead to the conclusion that the general principle of ownership by the States of the waters of navigable streams has not been decided, nor can it be expected that such a principle will be adopted by the courts because it is manifestly contrary to the fundamental idea of the Constitution that Congress shall have the power "to regulate commerce with foreign nations, and among the several States, and with the Indian tribes."

In the case of Gilman *v.* Philadelphia (3 Wall., 713–724) the United States Supreme Court held as follows:

"Commerce includes navigation. The power to regulate commerce comprehends the control for that purpose, and to the extent necessary, of all the navigable waters of the United States which are accessible from a State other than those in which they lie. For this purpose they are the public property of the nation, and subject to all the requisite legislation by Congress."

In the case of the United States *v.* The Rio Grande Dam and Irrigation Company (174 U. S., 690), there was involved the right of the company to operate under a grant of right of way approved by the Secretary of the Interior under the general right-of-way act of March 3, 1891. It was claimed that as the proposed reservoir would impound practically all the waters of the Rio Grande the effect upon navigation was injurious and the company should be prohibited from utilizing the grant claimed under the act of Congress.

The Supreme Court, after discussing several acts of Congress relating to the use of waters upon lands in the West, continues as follows:

"To hold that Congress by these acts meant to confer upon any State the right to appropriate all the waters of the tributary streams which unite into a navigable watercourse, and so destroy the navigability of that watercourse in derogation of the interests of all the people of the United States, is a construction which can not be tolerated. It ignores the spirit of the legislation and carries the statute to the verge of the letter and far beyond what under the circumstances of the case must be held to have been the intent of Congress." (P. 706.)

Proceeding then to discuss the act of September 19, 1890, prohibiting the obstruction of the navigable capacity of any waters over which the United States has jurisdiction, the court holds that—

"Any obstruction to the navigable capacity, and anything, wherever done or however done, within the limits of the jurisdiction of the United States which tends to destroy the navigable capacity of one of the navigable waters of the United States, is within the terms of the prohibition. Evidently Congress, per-

ceiving that the time had come when the growing interests of commerce required that the navigable waters of the United States should be subjected to the direct control of the National Government, and that nothing should be done by the State tending to destroy that navigability without the explicit assent of the National Government, enacted the statute in question. And it would be to improperly ignore the scope of this language to limit it to acts done within the very limits of navigation of a navigable stream." (P. 708.)

This case involved the waters of the Rio Grande within the limits of the Territory of New Mexico and it might therefore be doubted that it was intended to have a general effect and applicable to waters of navigable streams within the limits of States.

This is, however, not the case, because the decision rests upon the power of Congress over interstate commerce and is not based upon any principle which is applicable solely to the Territories.

This is made more evident by the illustration which the court gives in regard to the waters of the Hudson River, calling attention to the fact that it is a navigable stream, at least from Albany southward, and discussing the rights of the State of New York to appropriate the waters of its tributaries, stating that while the State might authorize the diversion of the waters of the tributaries of the Hudson and the United States may not question such appropriation unless the navigability of the Hudson be disturbed, yet if the State of New York should, even at a place above the limits of navigability, so diminish the volume of the waters as to destroy its navigability the jurisdiction of the National Government undoubtedly would arise and it would become the right of the Attorney-General to institute proceedings to restrain such appropriation. (P. 709.)

While the word "navigation" is not in the Constitution the word "commerce" comprehends it. (Gibbons *v.* Ogden, 9 Wh., 1–222.) Accordingly the States can have no power to exercise ownership or control over the waters of navigable streams that will in any manner interfere with the regulation of commerce by Congress. In the case of Gloucester Ferry Company *v.* Pennsylvania (114 U. S., 196–203) the United States Supreme Court held that the power to regulate commerce "is the power to prescribe the rules by which it shall be governed; that is, the conditions upon which it shall be conducted; to determine when it shall be free and when subject to duties or other exactions."

Congress has in many cases required payment for the use of the instrumentalities of commerce and navigation. Many instances may be cited, such as the charge of toll for vessels using canals, charges placed on immigrants, and the like. These are not taxes, but are in the nature of license charges.

The requirements of fees or charges of various kinds is inseparably connected with the power to regulate and has been so held in numerous instances.

This question was fully discussed in the Head Money Cases (112 U. S., 580). This case involved the constitutionality of the immigration act, requiring payment of a duty of 50 cents for every passenger brought into the country who was not a citizen of this country. The constitutionality of the act was upheld upon the ground that it was a proper form of regulation of commerce.

Objection was made to the act, among other things, that this duty of 50 cents per head was not a proper exercise of the taxing power conferred upon Congress by the Constitution. The court, however, held that this was not a tax, and said:

"We are clearly of the opinion that, in the exercise of its power to regulate immigration and in the very act of exercising that power, it was competent for Congress to impose this contribution on the shipowner engaged in that business."

The matter reduces itself to the following propositions, which seem self-evident. Congress has the power to regulate commerce between the States,

which includes navigation upon navigable waters; and the power to regulate the use of navigable waters includes the power to make appropriate charges for the use of all instrumentalities connected therewith.

A further comment on the same doctrine, by Charles Edward Wright, is as follows:[a]

In certain quarters it is denied that the United States has power to impose a charge in such a case. It is argued that the charge would be either a direct tax or in the nature of an impost or excise tax. If the former, it must be apportioned among the States rather than levied directly by the Federal Government itself; if the latter, it must be uniformly levied on every dam and water power in the entire country.

The latter objection, however, is not altogether sound. Uniformity, in the sense of the constitutional provision respecting taxation, means a geographical uniformity, the tax operating on all similar properties. That is, in every instance where the Federal Government approves the location and plans of a dam, thereby authorizing its construction, whether in a navigable waterway east, west, north, or south, the tax must be uniformly laid. But a water power developed on a nonnavigable stream, without let or license from the National Government, would stand in another category. Any rule of conformity would not necessarily involve the inclusion of such dams or water-power privileges; it would merely require the levy of such a tax upon every power privilege similarly authorized or confirmed by the Federal Government.

Recurring to the act of Congress establishing the California Débris Commission, already noticed in part, we find provisions for a "tax" which applies with no "geographical uniformity" throughout the country, but is restricted in operation to only a part of the State of California.

Briefly, the hydraulic process in mining may not be employed about the tributaries of certain navigable streams in that State without permit from the commission, the permit to be granted upon petition and hearing. The license, if granted by a majority of the board, embodies directions and specifications in detail as to the manner in which operations may proceed; what restraining or impounding works shall be built and maintained, and where they shall be located; "and in general set forth such further requirements and safeguards as will protect the public interests and prevent injury to the said navigable rivers, and the lands adjacent thereto, with such further conditions and limitations as will observe all the provisions of this act in relation to the working thereof *and the payment of taxes on the gross proceeds of the same. Provided*, That all expense incurred in complying with said order shall be borne by the owner or owners of such mine or mines." (Act of March 1, 1893, sec. 13.) The "taxes on the gross proceeds" are imposed by the twenty-third section of the act, which provides that the operators of the mines affected by the act "shall pay a tax of three per centum on the gross proceeds" of the mine so worked, said "tax" to be ascertained and paid in accordance with regulations to be adopted by the Secretary of the Treasury and to be paid into the Federal Treasury to the credit of the "débris fund," which shall be expended by said commission under the supervision of the Chief of Engineers and direction of the Secretary of War in the construction and maintenance of restraining works and settling reservoirs in aid of the purpose Congress had in mind in passing the act.

This act had been held to be constitutional, as already noted. Yet in terms it provides for the collection of a "tax" which is neither "apportioned" among

[a] The scope of state and federal legislation concerning the use of waters, by Charles Edward Wright, Assistant Attorney to the Secretary of the Interior: Annals Am. Acad. Polit. and Social Sci., 1909, pp. 577–581.

the States nor is levied by any rule of uniformity. Rather than a general excise law, it is one of special and circumscribed application. Still, the charge imposed is christened a "tax." If it were a tax, there can be little doubt of the unconstitutionality of the act. Wherein does such a "tax" differ from that to be charged upon the grant of special privileges for power purposes in a navigable stream? Both find their reason for existence in the conservation of navigation, although the miners may be required to pay for privileges connected directly with nonnavigable intrastate tributaries, while the power producers operate directly in the navigable stream itself.

But the charge is not a "tax" in the constitutional sense; it is of the nature of a license—the according of a special right or privilege to do a thing, which, without permission, would be unlawful. It is leave and liberty enjoyed as a matter of indulgence at the will of the Federal Government. * * *

The power to charge for a special privilege is not necessarily an exercise of the power to tax. It is rather the right to exact a quid pro quo. Public interests are bound to be jeopardized, even though certain advantages to a locality accrue from the establishment of the power plant. One has already been suggested—the operation of a lock; for the very fact that gives the Federal Government any measure of control—viz, the navigability of the stream—involves the conservation of navigation through artificial means. The charge imposed liquidates this that otherwise would be a burden in the nature of a tax upon the public. Aside from this, another potential element of cost to the public is involved—the possibility that the Government may be obliged to remove the obstruction caused by the building of the dam at its own cost. Ordinarily this has been guarded against by the exaction of a bond in a large penal sum, the burden of carrying which is an annual charge upon the owners of the franchise. What vital objection can there be to the adoption of a plan whereby the licensee, in lieu of annual tribute to a bonding company, pays such premiums into the Federal Treasury—a measure of insurance against the loss that might be occasioned were the franchise holder bankrupt and the needs of navigation were to require the removal of the dam? The fund created by the payment of these charges may be either devoted directly to the betterment of navigation, particularly in the removal of obstructions, or turned into the Treasury as a part of the general fund, indirectly serving the same purpose by relieving the taxpayer. If the Federal Government has the power to withhold approval, it has power to bestow approval upon such terms as it may deem necessary to impose in order to protect the present or future interests of the United States. If it has the power to exact a bond to protect the public against loss when, in the interest of navigation, it becomes necessary to remove the obstruction, it has the power to create a fund for the same purpose. If the public in general contribute to that fund, their contributions are in the nature of a tax. If, however, the special beneficiaries of the granted permission contribute to establish such a fund, it is not a tax, but a license charge, the sole similarity being that both are a rendering to Cæsar of the things that are Cæsar's.

Moreover, it is entirely competent for Congress to insist that no privileges[a] affecting navigable streams shall be granted to any corporation unless said corporation operates under a federal charter. The United States has authority to create a corporation as a means of carrying into effect any of its sovereign powers. (McCulloch *v.* Maryland, 4 Wheat., 316, 411.) Such a corporation may be authorized to construct a dam and lock in aid of navigation, and the incidentally developed power may be disposed of by the creature as well as by

[a] That is, privileges other than the use of the stream for natural navigable purposes.—C. E. W.

the sovereign itself—under such terms and conditions as Congress sees fit to impose. This would bring every power company using the navigable waters of the nation directly under the visitorial control of a federal commission—the Interstate Commerce Commission, for instance—with power to regulate charges and to prevent the formation of unlawful or monopolistic combinations. It is only natural that such companies should receive their corporate animation from the power which controls and regulates interstate commerce, because the ulterior purpose of their being, thus created, would be the production and transmission of power, in itself a feature of commerce which, in its development and utilization, will acknowledge no state bounds. In the incorporation of such companies, coupled with the grant of these privileges in the waterways of the nation, the imposition of charges, the tribute that the creature pays to its creator, will follow easily, logically, and lawfully.

GOVERNMENT DAMS ON NAVIGABLE STREAMS.

Another phase of the water-power situation on navigable streams appears at those points where, by reason of abrupt or excessive fall in the channel, it is necessary to canalize the river in order to make it possible or safe for navigation. Canalization involves the construction of a dam, and by such construction the United States is often the creator of a water-power site. It is probably true that the Government can not, by authority of the Constitution, construct water powers for commercial purposes, such powers as it is forced to construct in the canalization of a river being merely incidental to the purposes of navigation. But it has generally been conceded that, although the Federal Government does not own the corpus of the water, it does own the power that it creates, and it follows logically that it can and really does dispose of such power by lease. The practice, however, is not general, and the Government is by no means obtaining proper returns for the power that it has incidentally created, chiefly because many of the power sites are not yet in commercial demand. The reasons for this are numerous. At many of the dams shortage of water occurs during the summer season, and at such times the primary power is therefore reduced. At other points the amount of power available is limited by the low head afforded by the dams, and it will not therefore be utilized until the commercial demand is increased. Another reason is that many of the government sites are in unfavorable localities. Again, their development may be checked by the low price of fuel power. But these factors will not always be predominant, and we may expect a far greater demand for the power developed at government dam sites than there has been in the past if the difficulty existing at so many places, namely, the lack of water during dry seasons, is overcome. The construction by the Federal Government of reservoirs in the uplands and the preservation of forests would accomplish this end. Such reservoirs would clearly benefit navigation and they would at the same time incidentally benefit the water power. It thus appears that under some conditions

the Federal Government may have control over certain water powers on navigable streams by right of proprietorship.

According to a statement made by the Chief of Engineers, U. S. Army, to the National Conservation Commission in 1908, the power generated at government dams is sold to the amount of 3,243 horsepower, the revenue therefrom being $5,578.97. The power so used is located principally on Muskingum, Green, and Kentucky rivers in the Ohio Valley.

WATER POWERS ON THE PUBLIC LANDS.

Federal laws providing for the development of water powers on the public lands have so far consisted merely of clauses or phrases in certain land laws regarding rights of way. They provide for no regulation of water power, nor do they effectively prevent the diverse abuses that have grown up in connection with water-power operation and manipulation, except in the national forests, later to be discussed. The two principal laws relative to this matter are as follows:

[26 Stat., 1095.]

SEC. 18. That the right of way through the public lands and reservations of the United States is hereby granted to any canal or ditch company formed for the purpose of irrigation, and duly organized under the laws of any State or Territory, which shall have filed or may hereafter file with the Secretary of the Interior a copy of its articles of incorporation and due proofs of its organization under the same, to the extent of the ground occupied by the water of the reservoir and of the canal and its laterals, and 50 feet on each side of the marginal limits thereof; also the right to take from the public lands adjacent to the line of the canal or ditch material, earth, and stone necessary for the construction of such canal or ditch: *Provided*, That no such right of way shall be so located as to interfere with the proper occupation by the Government of any such reservation, and all maps of location shall be subject to the approval of the department of the Government having jurisdiction of such reservation, and the privilege herein granted shall not be construed to interfere with the control of water for irrigation and other purposes under authority of the respective States or Territories.

SEC. 19. That any canal or ditch company desiring to secure the benefits of this act shall, within twelve months after the location of 10 miles of its canal, if the same be upon surveyed lands, and if upon unsurveyed lands within twelve months after the survey thereof by the United States, file with the register of the land office for the district where such land is located a map of its canal or ditch and reservoir; and upon the approval thereof by the Secretary of the Interior the same shall be noted upon the plats in said office, and thereafter all such lands over which such rights of way shall pass shall be disposed of subject to such right of way. Whenever any person or corporation, in the construction of any canal, ditch, or reservoir, injures or damages the possession of any settler on the public domain, the party committing such injury or damage shall be liable to the party injured for such injury or damage.

SEC. 20. That the provisions of this act shall apply to all canals, ditches, or reservoirs heretofore or hereafter constructed, whether constructed by corpora-

tions, individuals, or association of individuals, on the filing of the certificate and maps herein provided for. If such ditch, canal, or reservoir has been or shall be constructed by an individual or association of individuals, it shall be sufficient for such individual or association of individuals to file with the Secretary of the Interior and with the register of the land office where said land is located a map of the line of such canal, ditch, or reservoir, as in case of a corporation, with the name of the individual owner or owners thereof, together with the articles of association, if any there be. Plats heretofore filed shall have the benefits of this act from the date of their filing, as though filed under it: *Provided*, That if any section of said canal or ditch shall not be completed within five years after the location of said section the rights herein granted shall be forfeited as to any uncompleted section of said canal, ditch, or reservoir, to the extent that the same is not completed at the date of the forfeiture.

SEC. 21. That nothing in this act shall authorize such canal or ditch company to occupy such right of way except for the purpose of said canal or ditch, and then only so far as may be necessary for the construction, maintenance, and care of said canal or ditch.

General Land Office regulations relative to the administration of the above-quoted act contain the following statements:[a]

3. *Control of water.*—While these acts grant rights of way over the public lands necessary to the maintenance and use of ditches, canals, and reservoirs, the control of the flow and use of the water is, so far as this act is concerned, vested in the States or Territories, the jurisdiction of the Department of the Interior being limited to the approval of maps carrying the right of way over the public lands. If the right of way applied for under this act in any wise involves the appropriation of natural sources of water supply, the damming of rivers, or the use of lakes, the maps should be accompanied by proof that the plans and purposes of the projectors have been regularly submitted and approved in accordance with the local laws or customs governing the use of water in the State or Territory in which such right of way is located. No general rule can be adopted in regard to this matter. Each case must rest upon the showing filed.

4. *Nature of grant.*—The right granted is not in the nature of a grant of lands, but is a base or qualified fee. The possession and right of use of the lands are given for the purposes contemplated by law, but a reversionary interest remains in the United States, to be conveyed by it to the person to whom the land may be patented, whose rights will be subject to those of the grantee of the right of way. All persons settling on a tract of public land, to part of which right of way has attached for a canal, ditch, or reservoir, take the land subject to such right of way, and at the total area of the subdivision entered, there being no authority to make deduction in such cases. If a settler has a valid claim to land existing at the date of the filing of the map of definite location, his right is superior, and he is entitled to such reasonable measure of damages for right of way as may be determined upon by agreement or in the courts, the question being one that does not fall within the jurisdiction of this department. Section 21 of the act of March 3, 1891, provides that the grant of a right of way for a canal, ditch, or reservoir does not necessarily carry with it a right to the use of land 50 feet on each side, but only such land may be used as is necessary for construction, maintenance, and care of the canal, ditch, or reservoir. The width is not specified.

[a] Regulations concerning right of way over public lands and reservations for canals, ditches, and reservoirs, and for use of right of way for various purposes; approved June 6, 1908, pp. 4, 5.

The second right-of-way act is entitled "An act relating to rights of way through certain park reservations and other public lands," approved February 15, 1901 (Stat. L., vol. 31, p. 790), as follows:

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That the Secretary of the Interior be, and hereby is, authorized and empowered, under general regulations to be fixed by him, to permit the use of rights of way through the public lands, forest and other reservations of the United States, and the Yosemite, Sequoia, and General Grant national parks, California, for electrical plants, poles and lines for the generation and distribution of electrical power and for telephone and telegraph purposes and for canals, ditches, pipes and pipe lines, flumes, tunnels, or other water conduits, and for water plants, dams, and reservoirs used to promote irrigation or mining or quarrying, or the manufacturing or cutting of timber or lumber, or the supplying of water for domestic, public, or any other beneficial uses to the extent of the ground occupied by such canals, ditches, flumes, tunnels, reservoirs, or other water conduits or water plants or electrical or other works permitted hereunder and not to exceed fifty feet on each side of the marginal limits thereof, or not to exceed fifty feet on each side of the center line of such pipes and pipe lines, electrical, telegraph, and telephone lines and poles, by any citizen, association, or corporation of the United States, where it is intended by such to exercise the use permitted hereunder or any one or more of the purposes herein named: *Provided*, That such permits shall be allowed within or through any of said parks or any forest, military, Indian, or other reservation only upon the approval of the chief officer of the department under whose supervision such park or reservation falls, and upon a finding by him that the same is not incompatible with the public interest: *Provided further*, That all permits given hereunder for telegraph and telephone purposes shall be subject to the provision of title sixty-five of the Revised Statutes of the United States, and amendments thereto, regulating rights of way for telegraph companies over the public domain: *And provided further*, That any permission given by the Secretary of the Interior under the provisions of this act may be revoked by him or his successor in his discretion, and shall not be held to confer any right, or easement, or interest in, to, or over any public land, reservation, or park.

FOREST SERVICE REGULATIONS.

The only water-power regulation attempted by the Federal Government is that exercised by the United States Forest Service on the national forests. Authority for such regulations is based on several federal laws relating to forest reservations, viz:

[Act of June 4, 1897 (30 Stat., 11).]

All the public lands heretofore designated and reserved by the President of the United States under the provisions of the act approved March 3, 1891, the orders for which shall be and remain in full force and effect, unsuspended and unrevoked, and all public lands that may hereafter be set aside and reserved as public forest reserves under said act, shall be as far as practicable controlled and administered in accordance with the following provisions.

* * * * * * *

The Secretary of the Interior shall make provisions for the protection against destruction by fire and depredations upon the public forests and forest reserva-

tions, which may have been set aside or which may be hereafter set aside, under the act of March 3, 1891, and which may be continued; and he may make such rules and regulations, and establish such service as will insure the objects of such reservations, namely, to regulate their occupancy and use and to preserve the forests thereon from destruction. * * *

A later law, approved February 15, 1901 (31 Stat., 790), already quoted on page 139, specifies further powers with reference to national forests. Under an act approved February 1, 1905, the execution of all laws relative to national forests, or forest reserves, as they were known at that time, was transferred to the Secretary of Agriculture, and it is section 5 of that act which, in the opinion of the Department of Justice, confirms the opinion that Congress did, in the previous act above quoted, clothe the Secretary of the Interior with authority to issue permits and make regulations for the establishment and maintenance of water powers therein. The text of section 5 is as follows:

That all money received from the sale of any product or the use of any land or resource of said forest reserves shall be covered into the Treasury of the United States and, for a period of five years from the passage of this act, shall constitute a special fund available until expended as the Secretary of Agriculture may direct, for the protection, administration, improvement, and extension of federal forest reserves.

In response to a request made by the Secretary of the Interior to the Department of Justice for an opinion as to the powers conferred upon said Secretary by the terms of these acts, Attorney-General (now Mr. Justice) Moody rendered the following decision on May 31, 1905:

Under the act of 1897 you are simply directed to so regulate the occupancy and use of these reservations as to insure the objects thereof and preserve the forests thereon from destruction. The act contains nothing inconsistent with the making of a reasonable charge on account of the use of the reserves under the permit granted by you. By the act of 1905 you are to cover into the Treasury money received from the "use of any land or resources" of the reservations, which "shall constitute a special fund * * * for the protection, administration, improvement, and extension of the federal forest reserves." Any sums of money realized in this connection would thus tend to preserve the forests and insure the objects of reservations, and it might therefore be contended that Congress, in authorizing you to regulate their use and occupation, considered the incidental question of charging for their use a proper subject to be left to your judgment and discretion. That such was the Congressional intent finds support in the fact that services somewhat analogous to compensation have been required for several years without any indication of a disapproval thereof on the part of Congress.

Furthermore, your power to prohibit absolutely the use or occupation of any forest reserve, when such action is deemed by you essential to insure its objects and preserve the forests from destruction, would probably be unquestionable, and that the authority to prohibit carries with it the right to attach conditions to a permission is well established. (22 Opin., 13, 27.)

In answer to your third question, therefore, I have to advise you that, in my opinion, you are authorized to make a reasonable charge in connection with the

use and occupation of these forest reserves, whenever, in your judgment, such a course seems consistent with insuring the objects of the reservation and the protection of the forests thereon from destruction.

Attorney-General Bonaparte, in a later opinion relative to this matter, under date of October 5, 1907, said:

The question under consideration in that case (referring to Attorney-General Moody's opinion above quoted) was whether you had authority to make a reasonable charge as a condition of a permit under the act approved June 4, 1897 (30 Stat., 35), which authorized the Secretary of the Interior to "make such rules and regulations and establish such service as will insure the objects of such reservations, namely, *to regulate their occupancy and use*, and to preserve the forests thereon from destruction."

It will be observed that neither of these acts conferred upon the Secretary of the Interior, expressly, any authority to make a charge of any kind as a condition of granting the permits which they respectively authorized. It was held, however, by Attorney-General Moody, that such authority was implied in the power conferred upon the Secretary by the act of 1897 to grant or refuse the permits, in his discretion, and the act of 1905 was referred to as substantially a legislative recognition of this authority on his part. If, however, the act of 1897 conferred upon the Secretary of the Interior, and therefore, afterwards, upon the Secretary of Agriculture, the authority in his discretion to require payment of a reasonable charge as a condition of issuing any such permits as are authorized by said act, it seems to me quite clear that the act of 1901, above quoted, conveys the like authority. The language of the later act appears to me more explicit than that of the former, and the intention of the Congress to leave the privileges granted under that act revocable in the discretion of the Secretary, as is expressly stated in the last proviso, above quoted, of the act of 1901, seems to be more nearly consonant with a purpose to intrust to his discretion all matters connected with the granting of such permits than is any relevant provision to be found in the act of 1897. I conclude, therefore, that you are authorized by the act of 1901 to make the granting of permits for the purposes contemplated by that act dependent upon the payment, by the persons receiving such permits, of such charges as you may deem reasonable for the purposes contemplated by the law.

Whether charges based upon the three grounds specifically enumerated in your letter requesting an opinion would or would not be reasonable is not, under the circumstances of this case, a question proper to be determined by this department, but a matter left by the law entirely to your discretion. In Riverside Oil Company *v.* Hitchcock (190 U. S., 325), referred to in the opinion of Attorney-General Moody, above quoted, the court says: "The responsibility as well as the power rests with the Secretary, uncontrolled by the courts." This would seem to be no less true as to the question presented in the present case.

It may be well for me to say, however, that I do not think it clear, as seems to be assumed in some of the papers forwarded with your letter, that no charge can be made for water used by persons to whom permits may be granted under the act approved February 15, 1901. Such persons, independently of their permits, would have no right or authority to appropriate the waters within the forest reserves; at all events, for such a purpose as the production of electric power. It is true that the Congress and the courts have recognized a right to appropriate water on the public lands under state laws or local customs, but lands within the forest reserves are not covered by general statutes referring to the public lands; and the right to use water on such re-

serves can be secured, it would seem, only under the provisions of the act approved June 4, 1897, and of other legislation specifically referring to the reserves, unless, perhaps, such rights existed before the particular reserve in question was created. I do not, however, consider it necessary to express a positive opinion on this subject, since I understand from your letter that you do not intend to consider the value of the mere use of the water itself in fixing the compensation to be paid as a condition for permits for its use.

I advise you, therefore, in conclusion that, in my opinion, you have the right to make what you believe to be a reasonable charge, as condition of issuing permits under the act of February 15, 1901, and that your determination is decisive as to what charge is or is not reasonable for such purpose.

Under the authority of the law construed by the Department of Justice as set forth above, the Forest Service enforces a power agreement upon parties making use of the national forests for the generation or transmission of water power or the construction of reservoirs for storage for water-power purposes. The form of the power agreement is as follows:

UNITED STATES DEPARTMENT OF AGRICULTURE.
FOREST SERVICE.

_____ Uses_____
(Name of forest.)

_____ Power_____
(Name of applicant.)

_____ _____
(Use applied for.) (Date of application.)

Power agreement.

CLAUSE 1. The _____ company, hereinafter called the permittee, a corporation organized and existing under the laws of the State, or Territory, of _____, and having its office and principal place of business at _____, in said State, or Territory, hereby applies for permission to occupy and use certain lands of the United States and rights of way reserved by the United States within the _____ National Forest, by constructing, maintaining, and operating thereon, for the purpose in this clause below set forth, the following works:

(Cancel such of the three following items (*a*), (*b*), (*c*) as may not be applicable.)

(*a*) _____ dam__ approximately _____ feet in height, respectively, and _____ reservoir__ to flood approximately _____ acres, whereof approximately _____ acres are national-forest land.

(*b*) _____ conduit__ approximately _____ miles in length, whereof approximately _____ miles will lie upon national-forest land or land within national forests over which a right of way for ditches or canals, constructed by the authority of the United States, is reserved by the act of August 30, 1890 (26 Stat., 391).

(*c*) _____ power house__ and appurtenant structures to occupy approximately _____ acres, whereof approximately _____ acres are national-forest land; all approximately as shown on _____ certain tracing_ , executed by _____ on _____, 19____, respectively, filed in _____ on _____, 19____, respectively, and marked by the designation hereto prefixed, which tracing _____ hereby made a part of this instrument.

The works for which a permit is hereby applied for are to be constructed, maintained, and operated for the purpose of storing, conducting, and/or using water for the generation of electric energy.

The permittee does hereby, in consideration for the permit hereby applied for, promise and agree for itself and its successors to comply with all regulations and instructions of the Department of Agriculture governing national forests, and especially with the following conditions:

CLAUSE 2. The permittee shall pay to the _____ National Bank of _____ (United States depositary), or such other government depositary or officer as shall hereafter be duly designated by the United States, to be placed to the credit of the United States, a construction charge of _____ dollars ($_____), annually in advance from _____ until the beginning of the use, for the purpose aforesaid, of the work or works for which permit is hereby applied for, being at the approximate rate of one dollar per acre and five dollars per mile for the land occupied by said works, at which time the permittee shall be entitled to a credit toward the operation charge hereinafter provided for of part of such annual construction charge so last paid, proportionate to the remaining part of the year for which such last payment was made; and annually thereafter a net operation charge fixed by the Forester and calculated as follows: The gross operation charge for any year shall be calculated by the Forester upon the basis of the quantity of electric energy generated in such year at a maximum rate which shall not exceed the following amounts per thousand kilowatt-hours:

	Cents.
For the first year	2
second year	4
third year	6
fourth year	8
fifth year	10
sixth to tenth years, inclusive	12½
eleventh to fifteenth years, inclusive	15
sixteenth to twentieth years, inclusive	17½
twenty-first to twenty-fifth years, inclusive	20
twenty-sixth to thirtieth years, inclusive	22½
thirty-first to thirty-fifth years, inclusive	25
thirty-sixth to fortieth years, inclusive	27½
forty-first to forty-fifth years, inclusive	30
forty-sixth to fiftieth years, inclusive	32½

CLAUSE 3. From the gross operation charge for any year, calculated as aforesaid, deductions shall be made as follows:

(*a*) A sum bearing approximately the same ratio to one-half such gross operation charge as the area of unreserved lands and patented lands on the watershed furnishing the water stored, conducted, and/or used in the works for which permit is hereby applied for bears to the total area of the watershed, as of the beginning of each year.

(*b*) A sum bearing approximately the same ratio to one-half such gross operation charge as the length of the conduit for which permit is hereby applied for upon unreserved lands and upon patented lands over which a right of way for ditches and canals is not reserved by the act of August 30, 1890 (26 Stat., 391), bears to the total length of such conduit, as of the beginning of each year.

(*c*) A sum bearing approximately the same ratio to the balance remaining after said deductions "*a*" and "*b*" as the quantity of electric energy generated from water stored artificially by the permittee over and above what is generated by the natural flow bears to all electric energy generated.

The sum remaining after all the aforesaid deductions have been made shall be the net operation charge for such year.

Provided, That the term "unreserved lands," as above used in this clause, shall be deemed and taken to mean lands of the United States not reserved as a part of any national forest, and that this permit shall not affect such lands or restrict in any manner the right and duty of the United States to control the occupancy and use thereof through the department or officer lawfully charged with their custody or control.

Provided further, That the term "patented lands," as above used in this clause, shall include all lands to which title has been perfected in persons, corporations, States, and Territories; also all lands outside the United States.

Provided further, That the word "conduit," as used in this and other clauses of this permit, shall include ditches, canals, pipe lines, and all other means for the conveyance of a flow of water.

CLAUSE 4. The decision of the Forester shall be final as to all matters of fact upon which the gross operation charge for any year, the deductions for such year, and the net operation charge for such year depend.

CLAUSE 5. The permittee shall install and maintain in good operating condition, free of any expense to the United States, accurate meters and other instruments approved by the Forester, adequate for the measurement of the electric energy on which said gross operation charge is to be calculated, and accurate measuring weirs and other devices approved by the Forester, adequate for the determination of the quantity of water used in the generation of electric energy from the natural stream flow and, separately, the quantity of water stored by the permittee so used over and above the natural stream flow; and the permittee shall keep accurate and sufficient records, to the satisfaction of the Forester and free of any expense to the United States, showing the quantity of electric energy generated in each year, the quantity of water used in such generation of electric energy from the natural stream flow, and, separately, the quantity of water stored by the permittee so used over and above the natural stream flow; and the authorized agents of the Forest Service shall at all times have free access to the aforesaid meters, weirs, instruments, devices, and records of the permittee. In case the permittee fails for any year to so install and maintain such meters, weirs, instruments, and devices, and to keep such records, the Forester shall fix by estimate the amount of the gross charge and of the deductions for such year, using such information as he can readily obtain.

CLAUSE 6. If the United States shall hereafter, for permits of this nature in national forests, reduce the general scale of maximum rates below those above provided for in clause 2 hereof, or shall wholly abolish charges for permits of this nature, then and thereupon the charges to be calculated and fixed hereunder, as provided in clause 2 hereof, shall be reduced or abolished in like degree.

CLAUSE 7. The permittee shall pay to the United States depositary or officer, as above set forth in clause 2 hereof, the full value of all merchantable live or dead timber cut, injured, or destroyed in the construction of the said works, title to which, at the time of such cutting, injury, or destruction, is in the United States, according to the scale, count, or estimate of the forest officer in charge or other duly authorized officer or agent of the United States, such full value of timber cut, injured, or destroyed in the construction of said works shall be deemed and taken to be, and payment therefor shall be made in advance as required by such forest officer or other duly authorized officer or agent of the United States.

CLAUSE 8. The permittee shall dispose of all brush and other refuse resulting from the necessary clearing of or cutting of timber on the lands occupied under the permit hereby applied for as may be required by the forest officer in charge.

CLAUSE 9. The permittee, its employees, contractors, and employees of contractors shall do all in their power, both independently and upon the request of the forest officers, to prevent and suppress forest fires.

CLAUSE 10. The permittee shall, on demand of the district forester or other duly authorized officer or agent of the United States, pay to the United States depositary or officer, as above set forth in clause 2 hereof, full value as fixed by such district forester or other duly authorized officer, for all damage to the national forests resulting from the breaking of, or the overflowing, leaking, or seepage of water from the works constructed, maintained, and/or operated under the permit hereby applied for; and for all damage to the national forests caused by the neglect of the permittee, its employees, contractors, or employees of contractors.

CLAUSE 11. The permittee shall build new roads and trails as required by the forest officer or other duly authorized officer or agent of the United States to replace any roads or trails destroyed by the construction work or flooding under the permit hereby applied for, and to build and maintain suitable crossings as required by the forest officer, or other duly authorized officer or agent of the United States, for all roads and trails which intersect the conduit, if any, constructed, operated, and/or maintained under the permit hereby applied for.

CLAUSE 12. The permittee shall within _____ months from the date of approval hereof, begin bona fide construction of the works for which permit is hereby applied for, and shall, within _____ years from the date of said approval, complete such construction and begin to operate said works for the purpose in clause 1 hereof set forth, unless the time is extended by written consent of the Forester; it being understood that such consent will usually be given only because of physical obstacles to construction, such as floods or engineering difficulties which could not reasonably have been anticipated.

CLAUSE 13. In constructing any dam or reservoir under the permit hereby applied for, the permittee shall follow the usual precautions in the ordinary methods of dam construction. This obligation, however, shall not be construed so as to relieve the permittee from any requirement of state law regarding the construction of dams and storage of water.

CLAUSE 14. The permittee shall sell electric energy to the United States when requested at as low a rate as is given to any other purchaser for a like use at the same time: *Provided*, That the permittee can furnish the same to the United States without diminishing the measured quantity of energy sold before such request to any other consumer by a binding contract of sale: *Provided further*, That nothing in this clause shall be construed to require the permittee to increase its permanent works or to install additional generating machinery.

CLAUSE 15. The permit hereby applied for shall be nontransferable (U. S. Rev. Stat., sec 3737) and shall be subject to all prior valid claims which are not by law subject thereto.

CLAUSE 16. No Member of or Delegate to Congress shall be admitted to any share or part of this agreement or to any benefit to arise thereupon. (U. S. Rev. Stat., secs. 3739 to 3742, inclusive.)

CLAUSE 17. No person undergoing a sentence of imprisonment at hard labor imposed by any court of the several States, Territories, or municipalities having criminal jurisdiction shall be employed in the performance of this contract. (Executive order, May 18, 1905.)

CLAUSE 18. The permittee shall, except when prevented by the act of God or the public enemy or by unavoidable accidents or contingencies, continuously operate for the generation of electric energy the works to be constructed under the permit hereby applied for, in such manner as to generate after such generation begins not less than the following percentages of the full hydraulic capacity of the said works measured in kilowatt-hours: In the first year _____ per cent; in the second year _____ per cent; in the third year _____ per cent; in the fourth year _____ per cent; in the fifth year _____ per cent; and in every year thereafter _____ per cent.

CLAUSE 19. If any of the works for which permit is hereby applied for shall be owned, leased, trusteed, possessed, or controlled by any device permanently, temporarily, directly, indirectly, tacitly, or in any manner whatsoever so that they form part of or in any way effect any combination or are in anywise controlled by any combination, in the form of an unlawful trust, or form the subject of any contract or conspiracy to limit the output of electric energy or in restraint of trade with foreign nations or between two or more States or Territories or within any one State or Territory, in the generation, sale, or distribution of electric energy, the permit hereby applied for shall be forfeited to the United States by proceedings instituted by the Attorney-General of the United States in the courts for that purpose.

CLAUSE 20. The permit hereby applied for shall cease and be void upon the expiration of fifty years from the date of approval hereof, but it may then be renewed in the discretion of the duly authorized officer or agent of the United States and upon such conditions as he may in his discretion fix: *Provided*, That such officer or agent, in fixing such conditions, shall consider the actual value at that time for power and all other purposes of the lands and rights of way within national forests occupied and used under the permit hereby applied for and the actual value at that time of all improvements lawfully made by the permittee within national forests under the permit hereby applied for, but neither the property of the permittee, if any, outside of national forests, nor the permit, franchises, bonds, capital stock, or other securities of the permittee shall be considered in fixing such conditions.

CLAUSE 21. Nothing herein contained shall be construed to prevent the Forest Service from having the same jurisdiction over the lands above specified, including the issuance of further permits, as over other national-forest lands, not inconsistent with the occupation and use hereby applied for.

In witness whereof the permittee has executed this application in duplicate at _____on this_____day of_____, 19__.

[SEAL.] By _____
President.

Attest:

_____
Secretary.

ACKNOWLEDGEMENT.

STATE OF_____ }
*County of*_____ } *ss.*

On this_____day of_____, 19__, before me, a notary public in and for said county, duly commissioned and sworn, my commission expiring_____, 19__, personally came_____, to me personally known, who being by me

duly sworn, did depose and say that he resides in_____; that he is the _____of the_____Company; that said company is the corporation which is described in and which executed the foregoing instrument; that he knows the seal of said corporation, that the seal affixed to such instrument is such corporate seal, that it was so fixed by order of the board of directors of said corporation, and that he signed his name thereto by like order; and the said _____acknowledged said instrument to be the free act and deed of said corporation.

Witness my hand and official seal the day and year first above written.

[NOTARIAL SEAL.] _____

Notary Public in and for_____County.

Approved_____, 19__, and permission granted subject to the conditions set forth.

_____

Forester.

STATE LEGISLATION.

Several States have begun to realize the necessity for water-power legislation. New York, Pennsylvania, Oregon, and certain other States have laws on this subject, which, so far as they go, are of good purport. Their principal defect is that they do not confer upon the authorities sufficient initiatory powers. Progress, in these three States especially, may be expected in the near future, but these isolated examples are not sufficient to establish a common policy. This country can not afford to be wise merely in spots. We will review briefly some of the state laws.

PENNSYLVANIA.

A water-supply commission of five members was created in the State of Pennsylvania under an act approved in May, 1905. This act gave the commissioners authority to collect information relative to the condition of the water supply and provided that no letters-patent should be issued to any company desiring to be incorporated for the purpose of supplying water to the public until the application had first received the indorsement of a majority of the commission.

An act approved in June, 1907, increases the scope of the commission's powers by providing that no application for the charter of a corporation for supplying water to the public or for the development of storage or transportation of water power for commercial and manufacturing purposes shall be approved until the same has received the approval of the water-supply commission, or unless such application shall contain the name of the river, stream, or other body of water from which it is proposed to take or use water or water power. The act also provides practically the same requirements in the case of agreements for the merger or consolidation of two or more corporations for the same purposes, and further provides that said cor-

porations, before merger, shall surrender all the rights theretofore existing to the Commonwealth. There is a further useful requirement that safeguards the stockholders of the companies proposing to consolidate, which provides that no such agreement of merger and consolidation shall be approved by said water-supply commission of Pennsylvania or by the governor until each of the corporations or parties thereto shall have placed in the office of the water-supply commission a written acceptance, under the seal of said corporation and authorized by a majority of the stockholders thereof, both of this act and of the act approved April 13, 1905, entitled "An act providing that the right of eminent domain, as respects the appropriation of streams, rivers, or waters, or the lands covered thereby, shall not be exercised by water companies incorporated under law," agreeing to be subject to and bound by the provisions of both of said acts, with like effect as if said corporations had been formed subsequently to the passage of both of said acts.

Another section of the act provides that no sale, assignment, disposition, or transfer of any franchise of a corporation theretofore or thereafter formed for the supply of water or water power shall be valid until the same has been formally presented to the water-supply commission of Pennsylvania and has received its approval. It is further provided that no corporation for the supply of water or water power, formed or created subsequently to the passage of the act, or subject to its provisions, requiring new or additional source of supply, shall acquire the same until the facts have been placed before the commission, especially the facts concerning the necessity for such new or additional source of supply, and have been approved by the commission and the governor, and a certificate has been issued.

The effect of the Pennsylvania law has been extremely beneficial to the State, and the commission and its agents have been able to collect a large amount of fundamental information that will in the future, as well as in the present, be of immense value to the people. The law now in force is merely a good beginning, and one of its principal benefits is to provide publicity of intent upon the part of water-power companies. Under it all the plans and proposals of development must be matters of public record, and a great advantage undoubtedly accrues by reason of the authority of the commission to deny its approval to plans and schemes that do not attain the standards established by the commission. Beyond this, however, the law does not go. It does not give to the commission the power to regulate rates at which power shall be furnished, nor does it establish any standard or classification of powers, such as is attempted under the French proposals. Undoubtedly, this development of the state power of regulation will be a matter of growth, and it is certain

that in spite of these omissions of the law, the Commonwealth of Pennsylvania is far in advance of all but a few States of the Union in matters of water-supply regulation and the relation thereof to the public.

NEW YORK.

The State of New York has enacted laws concerning water powers which, while they do not extend in the same direction as those of Pennsylvania, are none the less praiseworthy. In one respect the New York laws are far in advance of any others in this country, for they recognize and establish the interests of the State in water-power ownership and development.

The New York water-supply commission was originally constituted to control and regulate the establishment of municipal water supplies by municipal corporations or other civil divisions. The law provides that no such corporation shall have any power to acquire or take up lands for any new or additional sources of municipal water supply until plans, profiles, and specifications and a statement of needs for such supply shall have been approved by the commission. The law further provides an orderly course of procedure, by which these matters may be equitably adjudicated.

This commission was later given powers previously conveyed to a river-improvement commission, the object of which was to secure and provide means for the regulation of flow of water, the rectification of channels, and the making of reports on the best methods of accomplishing these purposes. This law gave to the commission an indirect relation to the water-power development of the State, but the final law, under which the commission is now acting, with reference to the development of water powers (chapter 569, laws of 1907) authorizes and directs the commission to devise plans for the progressive development of the water powers of the State, *for public use under state ownership and control.* The law directs that the commission shall proceed to collect information relating to the water powers of the State and shall devise plans for the development of such water powers as it deems available, and may devise plans for the development of such other water powers as shall be brought to its attention by the officers of municipalities. It further directs that detailed plans for such development shall be presented in reports made to the governor of the State, and that all other necessary information be furnished to enable the State to establish itself as a developer and owner of water power, for the public benefit.

The powers of the commission do not extend to the construction of reservoirs and water powers favorably reported on by it, a special act of the legislature being necessary in each case.

As in Pennsylvania, no power is conferred upon the commission to regulate the sale of water power, nor to control in any way the re-

lations between the owner of such power and the public which he serves with this utility. An indirect control may in some cases be effected if in the future the legislature shall provide for the construction of the storage works recommended.

The following statement [a] indicates clearly how the conditions impressed the members of the commission after they had expended a year in study of the subject under the guidance of one of the foremost engineers of the time. So general is the application of this statement that each of the States of the Union would do well to provide that copies of it be widely distributed among its citizens.

There are at this time opportunities for the State to acquire at a minimum cost the necessary lands and rights for the construction of large storage dams for the control of flood waters and for the development of water powers which can be made to yield generous returns to the people, if built, developed, and controlled by the State; but these same lands and rights will in a short time, like our forests, rapidly increase in price in the hands of private and corporate ownership. These valuable sites, like all natural resources, where nature has stored up immense treasure, grow more valuable each year as population becomes denser and the demand for their use increases.

We have only to look across our northern border to the Dominion of Canada to see how our mistakes in allowing private interests to acquire natural resources have been avoided by the statesmanship of the Dominion government. Another lesson may be learned from the policy of the Federal Government in obtaining a revenue from the national forests.

OREGON.

Two laws have recently been enacted by the legislature of Oregon relating to water rights, the beneficial use of water, and the development of water power. The first is an act providing a system for the regulation, control, distribution, use, and right to the use of water and for the determination of existing rights thereto within the State of Oregon, providing penalties for its violation, and appropriating money for the maintenance thereof and declaring an emergency. This law went into effect February 24, 1909. The second is an act providing for granting franchises of water power by the State and collecting fees therefor, in effect May 22, 1909.

The first law provides that, subject to existing rights, all waters within the State may be appropriated for beneficial use as provided therein and not otherwise, but nothing therein contained shall be so construed as to take away or impair the vested right of any person, firm, corporation, or association to any water. The State is divided into two water divisions, each under the charge of a superintendent, whose duties are to execute the laws relative to the distribution of water and to perform such other functions as may be assigned to him. He is vested with authority to make reasonable regulations to

[a] Third Ann. Rept. New York State Water-Supply Commission, 1908, pp. 300–301.

secure the equal and fair distribution of water in accordance with the determined water rights.

The acts provide for the creation of a board of control, to consist of the state engineer and the superintendents of the two water divisions above mentioned, to which is given supervision of the waters of the State and their appropriation, distribution, and diversion. Appeal from the decision of a superintendent of a water division is made to the board of control, and the decisions of said board are subject to appeal to the circuit and supreme courts of the State.

It is provided that on petition to the board of control, signed by one or more water users upon any stream requesting the determination of the relative rights of the various claimants to the waters of that stream, it shall be the duty of the board of control, if, upon investigation, it finds the facts and conditions are such as to justify intervention, to make a determination of said rights, and if suit is brought in the circuit court for a determination of rights to the use of water the case may, in the discretion of the court, be transferred to the board of control for determination. The act prescribes an orderly course of procedure in such cases, which includes suitable notice of proceedings, statements of claimants, taking of testimony, and all other features necessary to an equitable determination of the facts; provides for the entry of the decision of the board of control in the office of the county clerk of each county involved in the decision; and further provides that water-right certificates shall be issued by the board of control to the parties to whom water rights are granted in any case.

The act provides further that water divisions shall be divided by the board of control into water districts, each under the charge of a duly appointed water master, who shall divide the water of the natural streams and other sources of supply among the several ditches and reservoirs according to the rights of each party, and it further vests such water masters with the necessary legal authority and power of arrest.

The procedure prescribed relative to the appropriation of water within the State of Oregon is as follows:

SEC. 45. *Application.*—Any person, association, or corporation hereafter intending to acquire the right to the beneficial use of any waters shall, before commencing the construction, enlargement, or extension of any ditch, canal, or other distributing or controlling works, or performing any work in connection with said construction, or proposed appropriation, make an application to the state engineer for a permit to make such appropriation. Any person who shall willfully divert or use water to the detriment of others without compliance with law shall be deemed guilty of a misdemeanor. The possession or use of water, except when a right of use is acquired in accordance with law, shall be prima facie evidence of the guilt of the person using it.

SEC. 46. *Applications, nature of.*—Each application for permit to appropriate water shall set forth the name and post-office address of the applicant, the

source of water supply, the nature and amount of the proposed use, the location and description of the proposed ditch, canal, or other work, the time within which it is proposed to begin construction, the time required for completion of the construction, and the time for the complete application of the water to the proposed use. If for agricultural purposes, it shall give the legal subdivisions of the land and the acreage to be irrigated, as near as may be. If for power purposes, it shall give the nature of the works by means of which the power is to be developed, the head and amount of water to be utilized, and the uses to which the power is to be applied. If for the construction of a reservoir, it shall give the height of the dam, the capacity of the reservoir, and the uses to be made of the impounded waters. If for municipal water supply, it shall give the present population to be served and, as near as may be, the future requirements of the city. If for mining purposes, it shall give the nature of the mines to be served, the methods of supplying and utilizing the water. All applications shall be accompanied by such maps and drawings, in duplicate, and such other data as may hereafter be prescribed by the board of control, and such accompanying data shall be considered as a part of the application.

SEC. 47. *Applications, approval of.*—Upon receipt of an application it shall be the duty of the state engineer to make an indorsement thereon of the date of its receipt and to keep a record of the same. If upon examination the application is found to be defective, it shall be returned for correction or completion, and the date of and reasons for the return thereof shall be indorsed thereon and made a record in his office. No application shall lose its priority of filing on account of such defects, provided acceptable maps and drawings are filed in the office of the state engineer within thirty days from the date of said return to the applicant. All applications which shall comply with the provisions of this act shall be recorded in a suitable book kept for that purpose, and it shall be the duty of the state engineer to approve all applications made in proper form, which contemplate the application of water to a beneficial use, but when the proposed use conflicts with determined rights, or is a menace to the safety and welfare of the public, the application shall be referred to the board of control for consideration. It shall be the duty of the board of control to enter an order directing the refusal of such application, if, after full hearing, the public interest demands. An application may be approved for a less amount of water than that applied for, if there exist substantial reasons therefor, and in any event shall not be approved for more water than can be applied to a beneficial use. Applications for municipal water supplies may be approved to the exclusion of all subsequent appropriations, if the exigencies of the case demand, upon consideration and order by the board of control.

SEC. 48. *Application, how indorsed.*—The approval or rejection of an application shall be indorsed thereon and a record made of such indorsement in the state engineer's office. The application so indorsed shall be returned immediately to the applicant by mail. If approved, the applicant shall be authorized, on receipt thereof, to proceed with the construction of the necessary works, and to take all steps required to apply the water to a beneficial use, and to perfect the proposed appropriation. If the application is refused, the applicant shall take no steps toward the construction of the proposed work or the diversion and use of water so long as such refusal shall continue in force.

SEC. 49. *Assignment of permit.*—Any permit or license to appropriate water may be assigned, subject to the conditions of the permit, but no such assignment shall be binding except upon the parties hereto, unless filed for record in the office of the state engineer.

SEC. 50. *Limitation on time of completing work.*—Actual construction work shall begin within one year from the date of approval of the application and the construction of any proposed irrigation or other work shall thereafter be prosecuted with reasonable diligence and be completed within a reasonable time as fixed in the permit, not to exceed five years from the date of such approval. The board of control shall, for good cause shown, extend the time within which irrigation or other works shall be completed, or the right perfected under any permit which may be submitted for its consideration by the state engineer.

SEC. 51. *Appeals.*—Any applicant may appeal to the board of control for relief, which board may modify the decisions of the state engineer if it shall appear that he has abused the authority reposed in him by law. Such appeal shall be taken within thirty days from the date of such decision by the state engineer and shall be perfected when the applicant shall have filed in the office of the board a copy of the order appealed from, together with a petition setting forth the appellant's reason for appeal, and such appeal shall be heard and determined upon such competent proofs as shall be adduced by the applicant and such like proofs as shall be adduced by the state engineer. The state engineer shall not sit as a member of the board on such appeal.

SEC. 53. *Water-right certificate.*—Upon it being made to appear to the satisfaction of the board of control that any appropriation has been perfected in accordance with the provisions of this act, it shall be the duty of the board of control to issue to the applicant a certificate of the same character as that described in section 25. Said certificate shall be recorded and transmitted to the applicant, as provided in said section. Certificates issued for rights to the use of water for power development acquired under the provisions of this act shall limit the right or franchise to a period of forty years from date of application, subject to a preference right of renewal under the laws existing at the date of expiration of such franchise or right.

SEC. 54. *Date of right.*—The right acquired by such appropriation shall date from the filing of the application in the office of the state engineer.

SEC. 55. *Head-gate, maintenance of.*—The owner or owners of any ditch or canal shall maintain, to the satisfaction of the division superintendent of the division in which the irrigation works are located, a substantial head-gate at the point where the water is diverted, which shall be of such construction that it can be locked and kept closed by the water master; and such owners shall construct and maintain, when required by the division superintendent, suitable measuring devices at such points along such ditch as may be necessary for the purpose of assisting the water master in determining the amount of water that is to be diverted into said ditch from the stream or taken from it by the various users. Any and every owner or manager of a reservoir located across or upon the bed of a natural stream shall be required to construct and maintain, when required by the division superintendent, a measuring device of a plan to be approved by the state engineer, below such reservoir, and a measuring device above such reservoir on each or every stream or source of supply discharging into such reservoir for the purpose of assisting the water master or superintendent in determining the amount of water to which proprietors are entitled and thereafter diverting it for such appropriators' use. When it may be necessary for the protection of other water users, the division superintendent may require flumes to be installed along the line of any ditch. If any such owner or owners of irrigation works shall refuse or neglect to construct and put in such head-gates, flumes, or measuring devices after ten days' notice, the division superintendent may close such ditch, and the same shall not be opened

or any water diverted from the source of supply, under the penalties prescribed by law for the opening of head-gates lawfully closed, until the requirements of the division superintendent as to such head-gate, flumes, or measuring device have been complied with, and if any owner or manager of a reservoir located across the bed of a natural stream shall neglect or refuse to put in such measuring device after ten days' notice by the division superintendent, such superintendent may open the sluice gate or outlet of such reservoir and the same shall not be closed, under penalties of the law for changing or interfering with headgates, until the requirements of the division superintendent as to such measuring devices are complied with.

SEC. 65. *Water appurtenant to land for irrigation purposes.*—All water used in this State for irrigation purposes shall remain appurtenant to the land upon which it is used: *Provided*, That if for any reason it should at any time become impracticable to beneficially or economically use water for the irrigation of any land to which the water is appurtenant, said right may be severed from said land, and simultaneously transferred and become appurtenant to other land, without losing priority of right theretofore established, if such change can be made without detriment to existing rights, on the approval of an application of the owner to the board of control. Before the approval of such transfer an inspection shall be made by the proper division superintendent, who shall submit his report to the board of control, whereupon, by order, the board shall approve or disapprove such transfer and prescribe the conditions therefor. Such order shall be subject to appeal as in this act provided.

SEC. 66. *Unlawful use of water and waste.*—The unauthorized use of water to which another person is entitled or the willful waste of water to the detriment of another shall be a misdemeanor, and the possession or use of such water without legal right shall be prima facie evidence of the guilt of the person using it. It shall also be a misdemeanor to use, store, or divert any water until after the issuance of permit to appropriate such waters.

SEC. 67. *Obstructing works.*—Whenever any appropriator of water has the lawful right of way for the storage, diversion, or carriage of water, it shall be unlawful to place or maintain any obstruction that shall interfere with the use of the works or prevent convenient access thereto. Any violation of the provisions of this section shall be a misdemeanor.

SEC. 70. *Vested rights preserved.*—1. Nothing in this act contained shall impair the vested right of any person, association, or corporation to the use of water.

2. Actual application of water to beneficial use prior to the passage of this act by or under authority of any riparian proprietor, or by or under authority of his or its predecessors in interest, shall be deemed to create in such riparian proprietor a vested right to the extent of the actual application to beneficial use, provided such use has not been abandoned for a continuous period of two years.

3. And where any riparian proprietor or, under authority of any riparian proprietor or his or its predecessors in interest, any person or corporation shall, at the time this act is filed in the office of the secretary of state, be engaged in good faith in the construction of works for the application of water to a beneficial use, the right to take and use such water shall be deemed vested in such riparian proprietor: *Provided*, Such works shall be completed and said water devoted to a beneficial use within a reasonable time after the passage of this act. The board of control, in the manner hereinafter provided, shall have power and authority to determine the time within which such water shall be devoted to a beneficial use. The right to water shall be limited to the

quantity actually applied to a beneficial use within the time so fixed by the board of control.

4. Nor shall anything in this act contained affect relative priorities to the use of water between or among parties to any decree of the courts rendered in causes determined or pending prior to the taking effect of this act.

5. Nor shall the right of any person, association, or corporation, to take and use water be impaired or affected by any of the provisions of this act where appropriations have been initiated prior to the filing of this act in the office of the secretary of state, and such appropriators, their heirs, successors, or assigns, shall, in good faith and in compliance with laws existing at the time of filing this act in the office of the secretary of state, commence the construction of works for the application of the water so appropriated to a beneficial use, and thereafter prosecute such work diligently and continuously to completion, but all such rights shall be adjudicated in the manner provided in this act.

6. The board of control shall have authority, and shall for good cause, shown upon the application of any appropriator or user of water under an appropriation of water made prior to the passage of this act, or in the cases mentioned in subdivisions 3 and 5 of this section, where actual construction work has been commenced prior to said time or within the time provided in law existing at the time of filing this act in the office of the secretary of state, to prescribe the time within which the full amount of the water appropriated shall be applied to a beneficial use, and in determining said time shall grant a reasonable time after the construction of the works, or canal, or ditch, used for the diversion of the water, and in so doing shall take into consideration the cost of the appropriation and application of such water to a beneficial purpose, the good faith of the appropriator, the market for water or power to be supplied, the present demands therefor, and the income or use that may be required to provide fair and reasonable returns upon the investment. Upon making such order the board of control shall direct the state engineer to issue a certificate showing such determination. For good cause shown the board of control may extend the time by granting further certificates.

7. And where appropriations of water heretofore attempted have been undertaken in good faith, and the work of construction or improvement thereunder has been in good faith commenced and diligently prosecuted, such appropriations shall not be set aside or avoided, in proceedings under this act, because of any irregularity or insufficiency of the notice by law, or in the manner of posting, recording, or publication thereof.

8. All rights granted or declared by this act shall be adjudicated and determined in the manner and by the tribunals as provided in this act. This act shall not be held to bestow upon any person, association, or corporation, any riparian rights where no such rights existed prior to the time this act takes effect.

SEC. 72. *Eminent domain.*—The United States, the State, or any person, foreign or domestic corporation, or association may exercise the right of eminent domain to acquire for a public use any property or rights now or hereafter existing when found necessary for the application of water to beneficial uses, including the right to enlarge existing structures and use the same in common with the former owner. Any right of way so acquired shall be so located as to do the least damage to private or public property, consistent with proper and economical engineering construction. Such property or rights may be acquired in the manner provided by law for the taking of private property for public use.

The right to conduct water from or over the land of another for any public use, including the right to raise any water by means of dams, reservoirs, or embankments to a sufficient height to make the same available for the use intended, and the right to any and all land necessary therefor, may be acquired upon payment of just compensation in the manner provided by law for the taking of private property for public use.

The law providing for granting franchises of water power in the State of Oregon is as follows:[a]

An act providing for granting franchises of water power by the State, and collecting fees therefor.

Be it enacted by the people of the State of Oregon:

SECTION 1. All water within the State from all sources of water supply belong to the public.

SEC. 2. That every person, firm, or corporation, except municipal corporations (hereinafter called the appropriator), who shall appropriate water after the passage of this act for the purpose of applying the same to the development of power shall, during the life of such appropriation as fixed herein, pay to the State of Oregon not less than 25 cents or more than $2 per annum in advance, on or before the 2d day of January of each year, for each and every horsepower represented by the said appropriation. The amount of the payment shall be determined by the board of control and adjusted from time to time, based upon the percentage of power appropriated which is put to beneficial use. For the purpose of this act a horsepower is hereby defined to be 550 pounds of water per second of time for each foot of available fall.

SEC. 3. The appropriator shall pay to the board of control the fees required by section 2 of this act, proportionate to the remainder of the current year, and no appropriation of water for power purposes shall be deemed complete until such payment of fees is made. Immediately upon the receipt of such fees the board of control shall pay them over to the state treasurer, taking his receipt therefor, who shall place the same in the general fund of the state treasury. On or before the 2d day of January of each year thereafter every appropriator of water for power purposes shall forward to the board of control the fees provided for in section 2 of this act.

SEC. 4. Upon the completion of the appropriation of water for power purposes, as now or hereafter provided by law, and compliance with the provisions of this act, the appropriator thereof shall own and enjoy all of the uses thereof so long as he pays the annual fees therefor herein required, for a term not exceeding forty years from the date of appropriation, and shall have a preference right to reappropriate such water under such conditions as may be prescribed by law at the expiration of such term of years provided all fees have been paid. If any appropriator shall fail to pay any annual fee, or shall fail or refuse to renew the appropriation at its expiration, the State shall have a preference lien therefor prior to all other liens or claims, except for taxes, upon the improvements of the appropriator for developing and applying such appropriation of water and the real estate upon which the same are located, and upon notice from the board of control the attorney-general shall proceed to foreclose the lien and collect any unpaid fees in the same manner as other liens on real property are foreclosed, and the water shall be again subject to appropriation.

[a] Ch. 221, Laws of 1909 of the State of Oregon.

SEC. 5. Any person, firm, or corporation who believes himself or itself injured in any material right by any decision of the board of control shall have the right of appeal from such decision to the circuit court for the county in which the proposed appropriation of water is situated.

SEC. 6. In case the board of control is not created by law with power to supervise the appropriation, distribution, and use of the water of the State, then the duties imposed upon the board of control as prescribed by this act shall devolve upon and be assumed by the state engineer.

Filed in the office of the secretary of state February 24, 1909.

OTHER STATES.

Several other States of the Union have passed water laws which govern, in greater or less degree, the development of water power. Wyoming was the first State to enact a code of water laws, and Nebraska, Idaho, Utah, Nevada, North and South Dakota, Oklahoma, and New Mexico have laws that differ slightly but have the same purport. It will be unnecessary to review them, because the Oregon law, which is the latest, has already been quoted extensively.

CONCLUSIONS.

The water powers of this country have a higher ultimate significance than is generally conceded to them. They are certain to have a dominating effect upon the material progress and integrity of this Republic. In the Old World it has been decided to be a proper function of the Government to declare water powers of public utility and to place them under appropriate laws, the assumption being that the public has a dominant interest in the development of this great natural resource.

No one can safely predict the final form of laws to be enacted to this end. Whether they will lead to government ownership and control and whether, in this country, the State or the National Government shall control are matters for the future to determine. Our present form of government may prove to be all-sufficient in this respect. At least three European countries have found it necessary to make water power a national matter. This report is not to be considered as a plea for nationalization. The American author, at any rate, does not at present support that view, but he is impressed with the fact that necessity, and not legal precedent, must eventually direct the course of procedure. It can hardly be expected that when the necessity arrives it will be readily recognized and accepted. Acceptance will be postponed, at enormous cost, until the people can secure a clear vision above the mist of legal precedents. The great difficulty will not be to regulate water-power development and operation, but to convince the people that such regulation is necessary even though it may involve a change in our laws and our habits of thought.

The power sites of the West that are still in federal ownership present a suitable opportunity for the initiation of policies similar to those that have been found necessary in older countries. That the President of the United States appreciates this opportunity is indicated by the following extract from a special message on the conservation of natural resources, transmitted to the two Houses of Congress January 14, 1910:

With respect to the public land which lies along the streams offering opportunity to convert water power into transmissible electricity, another important phase of the public-land question is presented. There are valuable water-power sites through all the public-land States. The opinion is held that the transfer of sovereignty from the Federal Government to the territorial governments as they become States include the water power in the rivers, except so far as that owned by riparian proprietors. I do not think it necessary to go into a discussion of this somewhat mooted question of law. It seems to me sufficient to say that the man who owns and controls the land along the stream from which the power is to be converted and transmitted owns land which is indispensable to the conversion and use of that power. I can not conceive how the power in streams flowing through public lands can be made available at all except by using the land itself as the site for the construction of the plant by which the power is generated and converted and securing a right of way thereover for transmission lines. Under these conditions, if the Government owns the adjacent land—indeed, if the Government is the riparian owner—it may control the use of the water power by imposing proper conditions on the disposition of the land necessary in the creation and utilization of the water power.

The development in electrical appliances for the conversion of the water power into electricity to be transmitted long distances has progressed so far that it is no longer problematical, but it is a certain inference that in the future the power of the water falling in the streams to a large extent will take the place of natural fuels. In the disposition of the domain already granted, many water-power sites have come under absolute ownership, and may drift into one ownership, so that all the water power under private ownership shall be a monopoly. If, however, the water-power sites now owned by the Government—and there are enough of them—shall be disposed of to private persons for the investment of their capital in such a way as to prevent their union for purposes of monopoly with other water-power sites, and under conditions that shall limit the right of use to not exceeding fifty years, with proper means for determining a reasonable graduated rental, and with some equitable provision for fixing terms of renewal, it would seem entirely possible to prevent the absorption of these most useful lands by a power monopoly. As long as the Government retains control and can prevent their improper union with other plants, competition must be maintained and prices kept reasonable.

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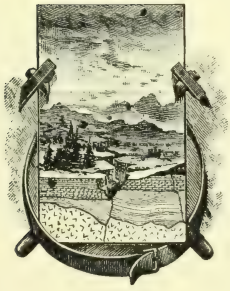
DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

WATER-SUPPLY PAPER 239

THE QUALITY OF THE SURFACE WATERS OF ILLINOIS

BY

W. D. COLLINS



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THE QUALITY OF THE SURFACE WATERS OF ILLINOIS.

By W. D. Collins.

INTRODUCTION.

OUTLINE OF REPORT.

This report furnishes the means of stating with fair accuracy the quality of water which may be found at any point along the larger streams within or bordering the State of Illinois. It also includes some explanation of the variations in the quality of the water at different times and places. The natural and economic features which determine the character of the streams are considered in a general way. The larger drainage divisions are described briefly. A short account of the distribution of population and principal industries of the State shows how these are affected by the streams and how they influence the quality of water in the streams. Methods of collecting and analyzing samples of water are described. The surface waters of the State were represented by samples taken at 27 different points. Each river is discussed in detail with reference to its source, course, discharge, and quality of water. The cities located on it are considered with reference to their use of and their effect on the water. Short chapters on municipal supplies and industrial uses of water save needless repetition in discussing the value of the water of each river. It is shown that the only large supplies of water in the State are surface waters. Nearly all the surface waters are so polluted as to be unfit for domestic use without purification. They usually contain such dissolved mineral matter and so much suspended material as to be unsuitable for many manufacturing purposes, but by proper treatment they may be rendered safe for drinking and suitable for all industrial uses. The proper purification of surface waters is in the greater part of the State the only way to obtain a large supply of satisfactory water. If in some way the flow of all streams might be regulated and kept more uniform, the increased uniformity in quality of the water would make much easier the problem of proper treatment.

The average amount of water used each day in cities of the United States varies from 50 to 150 gallons per capita. Of this the amount used for drinking is not much over one-half gallon. It is of the

greatest importance that this one-half gallon shall be free from the germs of disease, notably typhoid fever, and shall be reasonably clear and reasonably free from taste. This is all that is required to make this one-half gallon a satisfactory water. For many uses, as sprinkling streets, flushing sewers, etc., almost nothing is required in the way of purity. There is left for consideration a large number of other uses in which the value of the water depends on the amount and kind of mineral matter it contains. For use in laundries, in steam boilers, in textile works, and for the same kind of work at home, the best water is one which is clear, is free from iron, and contains only a moderate amount of other mineral matter.

NEED OF INVESTIGATION.

In time past the attention of those concerned with the quality of water has been directed very largely to the question of its fitness for drinking, but within the last few years corporations and communities have awakened to a realization of the great waste occasioned by the industrial use of unsuitable waters. The railroads of the country are spending thousands of dollars every year in treating their boiler-feed waters so as to render them less injurious to their boilers, the money thus spent being saved many times over in decreased cost of repairs and increased life of locomotive boilers. Many laundries find it profitable to install expensive apparatus for softening water, rather rather soften it with soap. Water must be purified for use in many woolen mills, breweries, and other establishments, while in some cities the whole city supply is softened.

In planning a waterworks system for home, factory, or municipality, it is not enough to know whether the water is safe for drinking. To determine the best water for all purposes, it is necessary to know the amount and character of the mineral matter it contains. Without such knowledge, no estimate can be made of the cost of purifying the water and making it suitable for drinking and for industrial uses. For most well waters a single analysis is enough to give a very accurate idea of the water which may be found in a given well, but the quality of the water in a stream varies so much that an opinion based on the results of an examination of a single sample of water from a given river would nearly always be very different from an opinion based on the results of a series of analyses, where the samples were taken regularly for some time.

PREVIOUS WORK.

A large amount of work had been done on the quality of river waters in Illinois before the beginning of this report. In Water-Supply Paper 194[a] M. O. Leighton has given a digest of the testimony

[a] Pollution of Illinois and Mississippi rivers by Chicago sewage: Water-Supply Paper U. S. Geol. Survey No. 194, 1907.

in the suit of the State of Missouri against the State of Illinois and the sanitary district of Chicago. As evidence in this case, results were presented from several thousand analyses of samples of water from Illinois River and its tributaries, with many analyses of Missouri and Mississippi water. The analyses made at that time were not analyses of the mineral constituents, but were mainly determinations of the amounts of certain substances present in very small quantities, usually less than 1 per cent of the total material dissolved in the water. These results merely indicated the purity of the water as regards sewage contamination and have little value for determining the value of the water for any use other than for drinking.

The Illinois State Water Survey, organized in 1895, has made a great many analyses of Illinois waters, but most of them have been for the purpose of determining the purity of waters for domestic use. Many analyses of the mineral content of waters have been made by the State Water Survey, but these are mainly of well waters.

The railroads of the State have made many partial analyses of all sorts of waters in their efforts to obtain for locomotive boilers those that are least injurious. The samples of the river waters are selected usually at random or in the driest seasons. Thus, with a very large number of partial analyses available, it was not possible to learn definitely just what might be expected in the way of water at any point on any river in the State.

COOPERATIVE WORK.

As part of an investigation[a] of the quality of surface waters in the United States, the waters of the State of Illinois were studied as one unit. A cooperative agreement for one year was entered into July 1, 1906, between the United States Geological Survey, the State Water Survey of Illinois, the engineering experiment station of the University of Illinois, and the State Geological Survey of Illinois. This agreement called for the investigation of mineral and organic constituents of the surface and ground waters of the State, together with experimental work on the action of waters in steam boilers, the purification of waters for industrial and domestic use, and other similar problems. Edward Bartow, director of the State Water Survey of Illinois, was designated as administrative director of the investigations to be carried on under the agreement. The writer was assigned to the investigation of surface waters, and began work in Illinois July 16, 1906. The points for the collection of samples had already been decided by the board of control of the cooperative work, consisting of M. O. Leighton for the United States Geological Survey, Edward Bartow for the State Water Survey, L. P. Breckenridge, Arthur N. Talbot, and Samuel W. Parr for the engineering experiment station, and

[a] Dole, R. B., Quality of surface waters in the United States, Part I: Water-Supply Paper U. S. Geol. Survey No. 236, 1909.

H. Foster Bain for the State Geological Survey. Arrangements were made at once for the collection of daily samples at 26 stations on rivers and at reservoirs, Doctor Bartow engaging collectors at the stations in the northern part of the State and the writer arranging for the collections on the rivers in the central and southern parts. Owing to lack of funds the United States Geological Survey was unable to renew the agreement for another year, so that the analytical work after June 30, 1907, was carried on by the other parties to the cooperation. This report gives the results of analyses of these samples of water, together with such other material as is necessary to make the figures of value.

ACKNOWLEDGMENTS.

The analyses of river waters were made in the laboratory of the Illinois State Water Survey by the writer until April 18, after which time they were made by Mr. C. K. Calvert. Other analyses have been obtained from the United States Geological Survey laboratories engaged in similar investigations in 1906–7. In the descriptive matter free use has been made of various publications of the Weather Bureau and the Bureau of the Census, and especially of the works of Palmer[a] and Leverett[b] on the waters of Illinois.

PHYSICAL FEATURES.

TOPOGRAPHY.

Illinois is a flat State. It is the lowest of the North-Central States, having a mean elevation of 600 feet, whereas that of neighboring States is from 700 to 1,100 feet.[c] In general, it slopes from north to south, with no pronounced changes in elevation. The most prominent ridge in the State is the Ozark uplift, in the southern part of the State, crossing from a point near Shawneetown, on the Ohio, to Grand Tower, on the Mississippi. This strip of elevated land, hardly 10 miles wide, stands about 300 feet above the neighboring tracts. The main features of the surface over the greater part of the State are due to the deposits of material left by the glaciers which once covered the State nearly to the Ozark uplift. In the lower portion, as far north as St. Louis, the drift is so thin as to exert little influence on the streams, but in the region north from St. Louis nearly all the stream courses are through this glacial drift. The elevations in this section show the amount of cutting which has been done by the streams.

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[a] Palmer, A. W., Chemical survey of the waters of Illinois, University of Illinois, 1904.

[b] Leverett, Frank, The Illinois glacial lobe: Mon. U. S. Geol. Survey, vol. 38, 1899.

[c] Leverett, Frank, The water resources of Illinois: Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1896, p. 703.

HYDROGRAPHY.

Except for the run-off of about 6,000 square miles in Wisconsin and about 3,000 square miles in Indiana and water from Lake Michigan equivalent to the drainage of 6,000 to 7,000 square miles, the rivers of Illinois carry only water precipitated within the boundaries of the State. Nearly all the drainage of the State is to the west and south into Mississippi River, but a small area is drained by streams flowing to the southeast into Wabash and Ohio rivers.

Rock River drains about 5,000 square miles in Wisconsin and a somewhat larger area in the northeastern part of Illinois. It discharges into the Mississippi at Rock Island.

Illinois River has the largest drainage basin in the State. The Chicago drainage canal and Desplaines, Kankakee, Fox, Vermilion, Mackinaw, Spoon, and Sangamon rivers all discharge into the Illinois, which carries into the Mississippi at Grafton the drainage from nearly half the State. The direct drainage into the Mississippi is small.

Kaskaskia and Muddy rivers drain the western half of the area from a little above St. Louis to the Ozark uplift.

Cache River is the largest stream draining the area below the Ozark ridge. The eastern half of the State, as far north as Champaign County, is drained into the Wabash through Vermilion, Embarrass, and Little Wabash rivers. Each of these streams will be considered in detail as regards the amount of flow, the quality of the water, and the value of the stream as a source of supply. Owing to the thorough cultivation of the land, the stream flow throughout the State is highly variable. There is nearly always a period of low water in the heated term, when the evaporation and absorption are greatest. During the winter, when the precipitation is light, the streams have another period of low water. The greatest floods occur in the early spring with the thawing of the ground, melting snow, and heavy rains. There is often a later flood in June and a slight rise above the normal in the early fall.

CLIMATE.

On account of the uniform elevation of the State, the climate is very largely determined by the latitude. The mean annual temperature decreases regularly from 58° at Cairo to 48° at Chicago. The mean temperature at Springfield is 52°. The summers are hot and the winters cold, the range of temperature being from about 105° to −20° F. The average annual rainfall is 36.5 inches. For the southern section the average is 39 inches, for the central district 36 inches, and for the northern district 34 inches. The period from August 1, 1906, to July 31, 1907, was one of exceptional rainfall, the average

for the State being 44.2 inches, 7.7 inches more than the mean annual rainfall. In every month of this period, except February, the rainfall in the State was nearly equal to or greater than the average. Table 1 shows the average temperature and rainfall for each month of the period.

TABLE 1.—*Average temperature and precipitation in Illinois, by months, August, 1906, to July, 1907.*[a]

Date.	Temperature.		Precipitation.	
	Average.	Departure from the mean of several years.	Average.	Departure from the mean of several years.
1906.	°F.	°F.	*Inches.*	*Inches.*
August	76.3	+2.4	4.01	+0.85
September	70.8	+3.8	5.10	+1.86
October	54.1	− .6	1.71	− .47
November	40.4	− .1	3.91	+1.28
December	32.7	+2.7	3.09	+ .87
1907.				
January	31.1	+4.8	5.69	+3.22
February	29.8	+3.3	.55	−1.66
March	47.9	+8.3	3.11	− .27
April	44.2	−7.6	2.76	− .30
May	56.7	−6.1	4.05	+ .05
June	68.4	−3.1	4.47	+ .38
July	75.7	.0	5.75	+1.89
		+7.8	44.20	+7.70

[a] Monthly Weather Review, U. S. Weather Bureau.

GEOLOGY.

All except the extreme southern part of Illinois is covered by glacial drift. This mantle varies in thickness from a few feet at the southern extremity to about 200 feet in the northern part of the State. It is made up of clay, gravel, and sand, with bowlders and in some sections layers of soil buried some distance below the surface. Alden,[a] in a study of this material in southern Wisconsin, made many analyses of the pebbles. He collected from 50 to 200 pebbles at random in a given region, divided them into groups according to the different kinds of rock represented, and calculated the percentage of each kind. In nearly every lot he found that over two-thirds of the pebbles were of some form of limestone very high in magnesium. With the exception of the rapid run-off immediately after a rain, the greater part of the water flowing in the rivers of Illinois has come through this glacial drift. The high magnesium content of the drift would account for the fact that the waters flowing in these streams contain a larger proportion of magnesium than do the waters of many other rivers.

[a] Alden, W. C., The Delavan lobe of the Lake Michigan Glacier: Prof. Paper U. S. Geol. Survey No. 34, 1904.

The glacial drift is a source of water supply for many of the inhabitants of Illinois. Over large areas in the north-central part of the State deep wells in the drift furnish an abundant supply of water. Beneath the drift the most important geologic division in the State is the Pennsylvanian series. This contains the coal which makes up so large a part of the natural wealth of Illinois. In the coal-bearing portions of the State there is very little underground water. Wells 10 to 20 feet deep furnish individual supplies, but cities have to rely on reservoirs which impound the drainage of small areas. The important water-bearing rocks are too deep to be easily reached, and where water has been found it has contained so much dissolved mineral matter that it has proved unsatisfactory.

In the northern part of the State two water-bearing formations are available as sources of supply—the St. Peter sandstone, of Ordovician age, and the older, deeper-lying Potsdam sandstone. The St. Peter sandstone appears at the surface in southern Wisconsin and dips rapidly to the south. It is a porous bed, and the water reaching it in southern Wisconsin is absorbed and transmitted southward. Where not drawn on too heavily, this water will rise nearly to the surface in Illinois when tapped by wells. Wells obtaining water from the St. Peter sandstone are about 1,000 to 1,500 feet deep, those farthest south being generally the deepest. In the northern part of the State, at depths of 2,000 to 2,500 feet, water is found in the Potsdam sandstone, which is the surface rock over much of central and northern Wisconsin. The thickness of this sandstone is not known, but it furnishes an abundant supply of water. The various limestone deposits between the St. Peter and Potsdam sandstones and above the St. Peter sandstone are used in only a few places as a source of water supply. As the Potsdam and St. Peter sandstones appear to be shallow-water or shore deposits they contain varying quantities of salts, so that in some places the waters that they yield are briny. At some places the St. Peter sandstone will furnish better water, while at others the Potsdam will do so.

ECONOMIC FEATURES.

POPULATION.

The distribution of population in Illinois is largely dependent on the surface water supplies. At the time of the census of manufactures in Illinois in 1905 all but 1 of 11 cities with 20,000 or more inhabitants were situated on Lake Michigan or on some of the larger rivers of the State. Of 21 cities with populations between 8,000 and 20,000 only 7 were not situated on a large river or the lake. This concentration of population in the cities located on streams and the lake may be due in part to the advantages of such locations

in the way of cheap transportation and power, but that factor can not be of great importance, for at the present time very little water power is utilized in the State, and transportation by water is of importance to very few cities. In all these cities, on the other hand, a large amount of water is used for manufacturing purposes, and the abundant supply available in such locations is undoubtedly one of the chief causes of their growth. Supplies of water from sources other than rivers and lakes are usually so small as to limit the population served by them to a low figure, beyond which increase is scarcely possible. This fact will always count strongly in favor of the river and lake cities in the establishment and extension of manufacturing plants and the increase of population necessary for conducting them.

AGRICULTURE.

On account of the richness of the soil the wealth of Illinois is very largely derived directly or indirectly from agricultural pursuits. The greater part of the State is covered with a rich black loam, which is especially well suited for growing corn. The southern part of the State does not have so rich a soil as the northern and central parts and produces somewhat more varied crops. The climate is favorable for raising cereals. In 1900 Illinois produced nearly 70 per cent of all the corn grown in the United States, 7 per cent of the wheat, and 22 per cent of the oats. This excessive production of corn accounts in some measure for the extent of the distilling industry in the State. The magnitude of the dairy business naturally follows from the great fertility of the soil. Many large dairy farms are necessary to supply Chicago and the other cities with milk and butter. In addition to supplying the demand within the State, the dairies of Illinois produce large quantities of butter and condensed milk, which are shipped to many different points in the United States.

MINES.

In addition to the wealth derived from the ground by growing plants, Illinois has a large store of mineral wealth under the ground in the form of coal, with smaller amounts of oil and lead and zinc ores and large amounts of undeveloped material, such as clays.

Nearly three-fourths of the State is underlain by productive coal measures. The working of the coal mines has, in some places, a very noticeable effect on the streams draining the mining regions. The effect of the mine drainage on streams in Pennsylvania has been carefully studied by M. O. Leighton.[a] In Illinois there are no such serious

[a] Quality of water in the Susquehanna River drainage basin: Water-Supply Paper U. S. Geol. Survey No. 108, 1904.

changes in the character of the streams. This is in some measure due to the facts that the mine regions of the State have less complete systems of drainage and that no large streams from outside flow through them. The effect of the sulphuric acid from the mine drainage may easily be seen in the analyses of the water from Muddy River at Murphysboro (Table 37). Here the value of the SO_4 radicle varies from 24 to 186 parts per million at different times of the year. The variation in the value of the SO_4 radicle in the water of the Mississippi at Chester was from 36 to 81 parts. The great variation in the character of the water coming from mining regions makes such water unsafe to use in steam boilers and very difficult to treat for purification either for drinking or for boiler use.

A large amount of limestone is quarried in the State. This industry has no effect on the water supplies.

Recently large amounts of oil have been produced in the southeastern part of Illinois, and the opening of the oil wells has had the usual effect on the streams. Similar conditions have been studied by Bowman[a] in the Indiana oil fields. Embarrass River, which drains the oil fields, has been affected by the salt water from the wells. In Indiana some streams have been so polluted by the waste waters from oil wells that they have been abandoned as sources of municipal supply.

MANUFACTURES.

As a manufacturing State Illinois has many great advantages. Its central location makes easy the procuring of raw materials and the distribution of manufactured products. The transportation facilities of the Great Lakes and Mississippi River are of great value. Additional improvements in river courses may in time greatly increase the ease of marketing the output of the factories of the State. Illinois is very well covered by railroads which furnish transportation for raw and manufactured materials. The railroads are so numerous and the State so centrally located that they made the manufacture and repair of cars and general railroad-shop construction the twelfth industry in importance in the State at the census of 1905. As already mentioned, the natural wealth of the soil furnishes material for the manufacture of liquors, dairy products, and a small fraction of the meat products of the State.

The largest industry in Illinois is slaughtering and meat packing. In 1905 Illinois produced one-third the total value of meat products of the United States, 85 per cent of this amount being produced in Chicago. The other leading cities in this industry were Peoria and

[a] Bowman, Isaiah, The disposal of strawboard and oil-well wastes: Water-Supply Paper U. S. Geol. Survey No. 113, 1905.

East St. Louis. The nuisance resulting from the slaughtering industry in Chicago was a large factor in bringing about the construction of the Chicago drainage canal, the operation of which has had a marked effect on the amount and quality of water flowing in Illinois River.

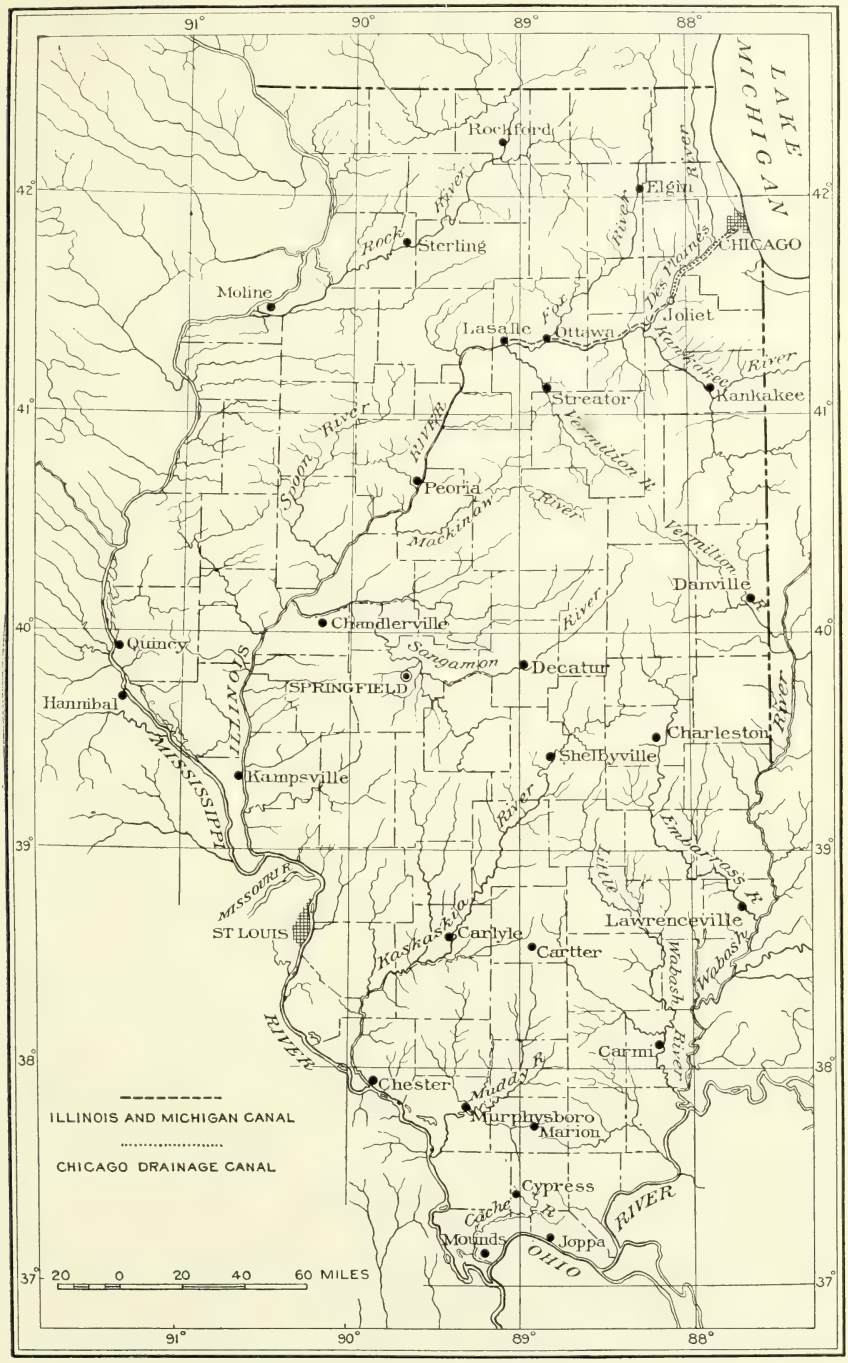
Next in importance is the iron and steel industry. The extensive supply of coal makes it possible to take advantage of the ease with which iron ore can be procured and to build up the great industrial centers for the manufacture of iron and steel products. The leading cities in this industry were Chicago, East St. Louis, and Joliet. Twenty-seven establishments reported the use of 334 steam engines of 155,348 total horsepower, or an average of 5,743 horsepower for each establishment. To furnish feed water and condenser water for over 5,000 horsepower would require more than the whole supply of many small cities dependent on underground waters. Although there are several other requirements that might be important enough to be determining factors in the location of such plants, the need of water is enough in itself, and in Illinois the necessary supply of water can be obtained only from a large stream or lake.

Foundry and machine-shop products are next in value to the iron and steel products. The establishments are located in about the same places as the iron and steel mills, and are the next largest users of steam power.

The next industry in importance is the manufacture of distilled and malt liquors. Of eleven distilleries in the State, six are located in Peoria. These six produced in 1905 nearly 78 per cent of all the distilled liquors produced in the State and 32 per cent of the total quantity produced in the United States. The chief product is whisky, made from corn, which is grown in great abundance throughout the State. The manufacture of malt liquors is not so concentrated, extensive establishments being located in most of the large cities.

The waste materials from distilleries and breweries in great part find their way finally to the rivers. In some places they are discharged directly into the streams; in others they are fed to cattle and thus indirectly furnish a large amount of organic matter to the streams.

The manufacture of clothing, flour and gristmill products, agricultural implements, railroad cars, furniture, and some of the other more important products is less influenced by and has less influence on the waters of the State.



MAP OF ILLINOIS SHOWING SAMPLING STATIONS.

SURFACE WATER SUPPLY.

QUALITY OF WATERS.

COLLECTION OF SAMPLES.

In accordance with the plan outlined on page 7 samples of water were collected daily from 17 rivers and reservoirs at 27 different points in the State. These points of collection are shown on the map (Pl. I). Four-ounce samples were taken each day for one year, beginning August 1, 1906, except at Moline, where the first sample was taken February 1, 1907; at Marion, where none were taken after March 20, 1907; and at other stations where collections were omitted for brief periods. When possible, the 4-ounce sample bottles were rinsed several times and filled from pumps taking water from the river or reservoir. Where there was no pump at the point of collection, water to fill the bottles was dipped from near the surface, or else the bottle was let down with a sinker and filled some distance below the surface. The last method would give the most accurate sample if the bottle were filled at exactly the right point in the cross section of the river, but the samples from pumps represented the water actually obtained in practice and the kind likely to be obtained by other pumps. The 4-ounce samples were sent each day to the laboratory of the Illinois State Water Survey at Urbana. A label on the bottle gave the date, the initials of the collector, the name of the station, and (where the gage height was obtainable) the stage of the river.

ANALYTICAL METHODS.

When the 4-ounce samples were received in the laboratory, all from one station for ten days were united in a half-gallon bottle. After about November 1 the samples from a station received during each third of a month were united, whether there were more or less than 10. This made all the composites complete for the same periods and simplified the handling of the samples. Determinations were made on each composite sample, as follows:

Turbidity was determined with the Jackson electric turbidimeter for values over 100 parts per million. For values between 100 parts and 50 parts comparison was made with silica standards in 500 cubic centimeter clear-glass bottles. For values below 50 parts, the standards were kept in bottles of the same kind as those holding the composite samples.

Suspended matter was determined by filtering from 100 to 500 cubic centimeters through an asbestos mat in a porcelain Gooch crucible, drying for an hour at 180°, and weighing. Some of the samples contained finely divided matter which could not be removed by the asbestos mat, thus giving too low a value for the suspended matter.

Dissolved solids were obtained by weighing the residue from the evaporation in platinum of 500 cubic centimeters of filtered water.

Silica, iron, and aluminum were separated from the total residue in the usual manner. The silica was weighed and volatilized with hydrofluoric acid. As a rule the iron and aluminum precipitate was dissolved in hydrochloric acid and the iron determined colorimetrically with potassium sulphocyanide and by comparison with permanent standards.

Calcium and magnesium were determined in half the filtrate from the iron and aluminum precipitate. The calcium was precipitated as oxalate, dissolved in sulphuric acid, and titrated hot with potassium permanganate. Magnesium was precipitated as ammonium-magnesium phosphate; after standing overnight the precipitate was washed and dissolved in dilute nitric acid. This solution was made alkaline to methyl orange with ammonia and nitric acid added to make it barely acid. Sodium acetate was then added and the phosphoric acid titrated with uranium nitrate, with potassium ferrocyanide indicator. In some of the early analyses the addition of the phosphate was made in alkaline solution. These precipitates may have contained more phosphate radicle than the amount corresponding to ammonium-magnesium phosphate. In such a case titrating the phosphoric acid would give too high a value for the magnesium.

Sulphate and alkalies were determined in the other half of the filtrate from the iron and aluminum precipitate. The sulphate was precipitated and weighed as barium sulphate. The sodium and potassium were weighed as chlorides after the removal of magnesium, calcium, and barium by barium hydroxide, ammonium hydroxide, and ammonium carbonate. Sodium and potassium were not separated.

Nitrate was determined by the phenol-sulphonic acid method.

Chlorine was determined by evaporating 100 cubic centimeters of filtered water down to 25 cubic centimeters, adding potassium chromate, and titrating with silver nitrate solution. The strength of silver nitrate solution was such that 1 cubic centimeter represented 5 parts per million of chlorine.

Carbonates and bicarbonates were determined by titration with fiftieth-normal acid potassium sulphate solution, using phenolphthalein and methyl orange indicators. No sample during the first two months was found to be alkaline to phenolphthalein, so its use was discontinued throughout the rest of the year, except for occasional samples, none of which was found to be alkaline to phenolphthalein.

For the first month all the analytical work was done by the writer. After that time assistance was furnished by the State Water Survey. Until April 1, 1907, all the titrations and color comparisons and most

LEGEND

Cache River at Mounds

DIAGRAM SHOWING COMPOSITION OF MATERIAL CARRIED BY ILLINOIS WATERS

of the weighings were made by the writer. Much of the other work was done by assistants without much knowledge of chemistry, but with considerable skill in manipulation. C. K. Calvert conducted the analytical work from April 20, 1907, till the completion of the analyses of the samples collected July 31, 1907.

RESULTS.

The results of the analyses are given in Tables 19 to 45, each table containing all the analyses for one station with the averages for the year and average gage readings for stations where gages were maintained. Table 46 contains the averages for the year for all the stations. Plate II shows graphically the composition of the dry residue from the evaporation of filtered water and Plate III the relative amounts of dissolved and suspended matter. The analytical results are expressed as radicles—that is, elements or combinations of elements which take part in chemical reactions as if they were elements. Although no one can state positively how these radicles are combined in the water, and the general opinion is that to a considerable extent they are uncombined, nevertheless the metallic or basic radicles, as calcium, magnesium, and sodium must be present in quantities equivalent to the total quantity of acid radicles—chlorine, nitrate, sulphate, and bicarbonate radicles. In a careful analysis the sum of the radicles as determined minus the half-bound carbonic acid will be nearly equal to the weight of the residue at 180° C. On account of the large number of analyses made in a short time and the amount of work done on them by persons who were not chemists, many of the analyses when completed would show that they did not represent accurately the character of the water. Many analyses were not complete on account of the small number of daily samples received during the ten-day period. The omission of analyses or determinations in the tables of results is due largely to failure to receive the samples, though some samples were lost in the laboratory and a few determinations have been rejected because they show very clearly that they are erroneous.

DETAILED INVESTIGATIONS.

LAKE MICHIGAN.

Drainage.—Lake Michigan receives the drainage of only a very small portion of Illinois. The amount of water carried from the lake by the Chicago drainage canal is much greater than that received from the small area of the State draining into the lake. The greater part of the drainage into the lake enters from Michigan and Wisconsin. The total area of the Lake Michigan drainage basin is estimated

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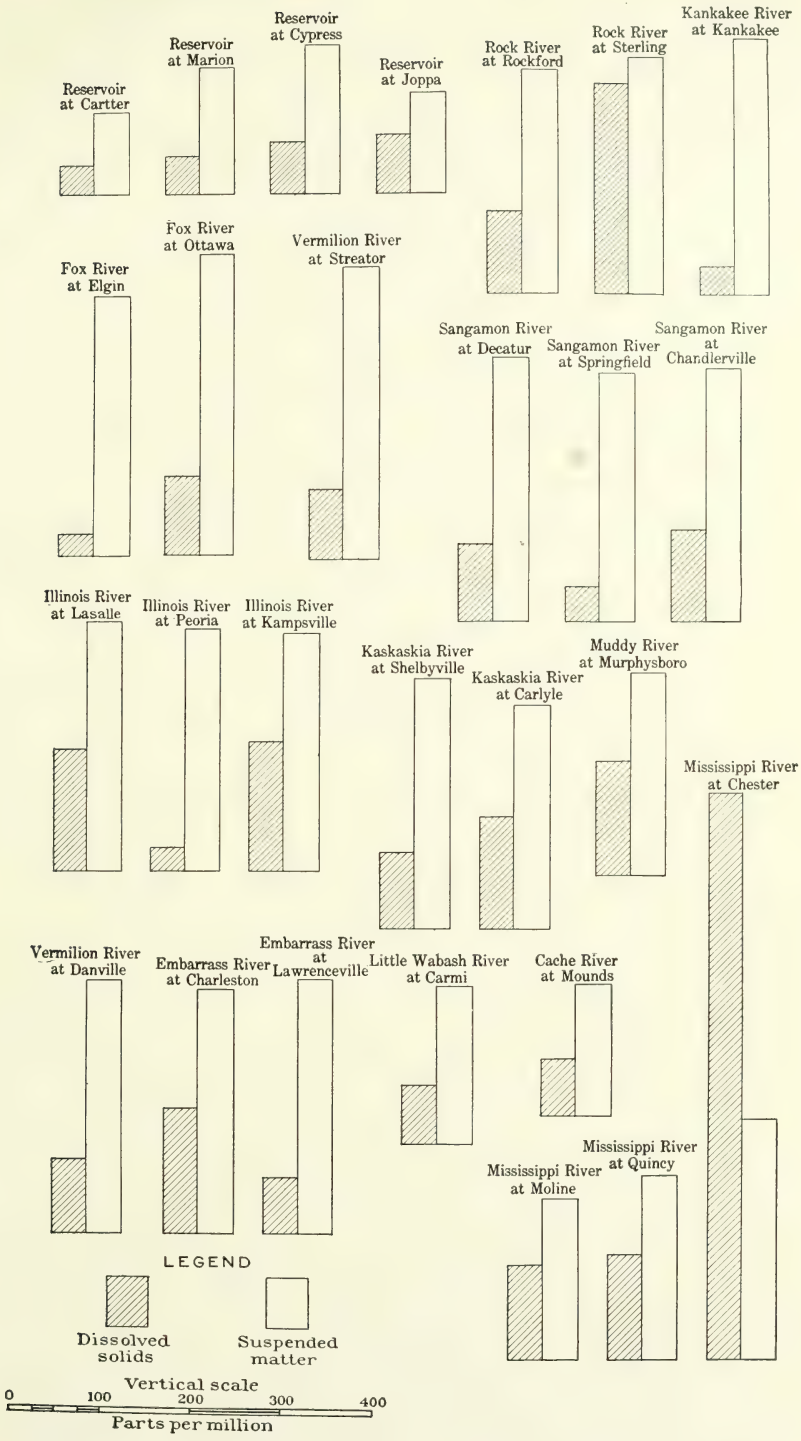
at 68,000 square miles, of which 22,400 square miles is lake area. Thus, if the rainfall were uniform over the whole basin, about one-third of the water reaching the lake would be pure rain water. This would cause a notable dilution of the water fed to the lake by streams emptying into it. To a certain extent the effect of this dilution is counteracted by the greater evaporation from the lake surface than from the surrounding land.

Municipal supplies.—Along the shore of the lake are situated establishments furnishing over one-half the manufactured articles produced in the State. Most of these industries are located in Chicago, but there are important factories at Evanston, Waukegan, and other cities along the shore. The leading position of Chicago as a manufacturing center is due in large measure to her excellent railroad facilities, but the lake transportation is of importance to certain industries. Hardly any other source in Illinois would supply enough water for the manufactories bordering the lake, and no other source could offer water of so good a quality except in comparatively small quantity. More water is used from Lake Michigan than from any other single source in Illinois. The cities of Chicago, Evanston, Fort Sheridan, Highland Park, Lake Forest, North Chicago, Pullman, Waukegan, West Hammond, and Winnetka, with a total population of 3,000,000, draw their municipal supplies from the lake. All along the lake front there is a supply of underground water at depths of 1,000 to 2,000 feet, but in many places this water, while safe to drink, contains so much dissolved mineral matter as to render it unfit for most industrial uses. This deep-well supply, however, is not sufficient for any large community.

Quality of water.—In the past there has been danger in the use of the lake water for drinking because the intakes were too near the shore and sewage was allowed to flow into the lake. The opening of the Chicago drainage canal was a great advance in keeping the water of the lake pure, and there is now a steady effort to prevent pollution. As the lake water is sufficient for any community and is almost the best water available in the State for industrial uses, it naturally follows that all the cities and States located on the lake have a vital interest in keeping the water pure enough for domestic use.

The water of Lake Michigan has been so carefully studied in former years that no analyses were made for this report. The character of the lake water is nearly constant, so that one analysis is as good as a large number.

Certain determinations were made on the Chicago city supply for a number of years in connection with work on the Chicago drainage canal. Analyses were made of samples collected each week from



DIAGRAMS SHOWING RELATIVE AMOUNTS OF DISSOLVED AND SUSPENDED MATERIAL CARRIED BY ILLINOIS WATERS.

January 4, 1897, to December 26, 1900. The average values for dissolved solids and chlorine for the years stated were as follows:[a]

TABLE 2.—*Partial analyses of Chicago city water supply.*

[Parts per million.]

Period.	Dissolved solids.	Chlorine.
1897	136.6	2.9
1898	137.6	3.2
1899	132.0	3.1
1900	132.2	3.3
May 1–October 30, 1888	136.4	2.1

These results would indicate that the amount of mineral matter in the water of Lake Michigan at Chicago does not vary much from year to year. Below is given an analysis by Long of the mineral content of the lake water:

Analysis of Lake Michigan water.[b]

	Parts per million.
Silica (SiO_2)	5.2
Iron (Fe)	.24
Calcium (Ca)	32
Magnesium (Mg)	11
Sodium and potassium (Na+K)	2.3
Carbonate radicle (CO_3)[c]	73
Sulphate radicle (SO_4)	7.2
Chlorine (Cl)	2.3

With the exception of certain small reservoirs, no supply of water in the State contains less dissolved mineral matter than the lake water. Most of the waters used in the State contain twice as much of material that will form scale in steam boilers, and nearly all are much more turbid than the lake water as delivered to the consumers in the cities where it is used.

RESERVOIRS.

Distribution and use.—Throughout the greater part of southern Illinois there is no abundant supply of water. Individual needs are met by shallow wells, which are liable to fail in dry weather and which do not furnish enough water for large communities. In this section of the State there is no underground water that is available and suitable for domestic and industrial use. Thus municipalities not located on streams of good size have been compelled to obtain

[a] Long, J. H., Chemical investigations of water supplies of Illinois, 1888–89.
[b] Long, J. H., op. cit., 1885, p. 7.
[c] Probably present as the bicarbonate radicle; equivalent to 148 parts HCO_3.

their supplies through the use of impounding reservoirs. Eleven cities, with a population of 26,000, obtain their city supplies from such reservoirs.

Samples.—Through the kindness of R. S. Charles, division engineer of the Chicago and Eastern Illinois Railroad, at Salem, Ill., arrangements were made for the collection of samples from reservoirs used as sources of locomotive feed water. Collections were made at Cartter, Marion, Cypress, and Joppa. Some difficulty was experienced in obtaining samples regularly from Marion; and as the water from Marion was much the same as that from the other three reservoirs, collections at this station were discontinued after March 20, 1907.

Quality of water.—Analyses of the composite samples from these four reservoirs are given in Tables 19, 20, 21, and 22. All four furnish a very satisfactory water for boiler purposes. The greater part of the time they contain large amounts of finely divided yellow or brown silt, which is very difficult to remove by any method of filtration. This is the same material that is found in the water from Little Wabash, Muddy, and Cache rivers. Marion is located in the midst of a mining section, a fact that probably accounts for the high value for sulphate in the analysis of the water from the Marion reservoir. For use in boilers or in any place where the color and turbidity do not detract from the value of the water, the water from the reservoirs at Cartter and Joppa is considerably better than that from Lake Michigan. These natural reservoirs give the softest water obtainable in the State, except that from carefully constructed artificial reservoirs.

ROCK RIVER.

Drainage.—Rock River rises in Wisconsin, between the upper Fox and the south end of Lake Winnebago, and flows in a southwesterly direction till it enters the Mississippi near Rock Island. The length of the river is nearly 300 miles and the drainage area approximately 11,000 square miles. About half the length and drainage area are in Wisconsin. In the upper part of the drainage basin there are numerous lakes and swamps, which tend to equalize the discharge of the river throughout the year. Practically all of the course of the river is in glacial drift. (See p. 10.) In Illinois the banks of the river expose the Silurian and Ordovician formations down to and including the St. Peter sandstone. The uniform character of the bed makes an even distribution of fall throughout its course. From its source to the point where it empties into the Mississippi there is a fall of 340 feet, making an average slope of 1.2 feet to the mile. The greatest fall in Illinois for any considerable distance is from Oregon to Sterling and Rock Falls, a distance of 36 miles, in which the average slope is 1.31 feet to the mile. In Wisconsin there is one stretch of 30 miles with an average slope of 1.9 feet to the mile. Locally there are even higher grades.

There have been many power developments along the river, and some of the power is utilized at the present time. For the sake of the power users, the flow is regulated to a certain extent at some of the lakes in Wisconsin. The discharge of Rock River has been studied at various points in order to determine the available water power. During the period covered by the analyses in this report the only gagings made were at Rockton, where the United States Geological Survey has maintained a gage since October 1, 1906. Gage readings had been made at Rockton during parts of several previous years, but the station was discontinued July 1, 1906, so that during the months of August and September, while samples were being collected for analysis, no gage readings were taken. From the gage readings and rating table of the Geological Survey discharges were calculated for each day from October 1, 1906, to July 31, 1907. The average discharge at Rockton for that period was 4,430 cubic feet per second. As Rockton is about halfway down the drainage basin from the source of the river, the average discharge into the Mississippi was probably from 8,000 to 9,000 second-feet.

Industrial uses.—Rockford, the largest city on Rock River, is situated about 20 miles south of the Wisconsin line. Its chief industries are the manufacture of furniture, hosiery and knit goods, agricultural implements, foundry and machine-shop products, and glucose.[a] Other cities of over 1,000 inhabitants situated on Rock River, mostly at water-power sites, are Byron, Oregon, Dixon, Sterling, Rock Falls, and Prophetstown. Sterling and Rock Falls, being just across the river from each other, form one community for many purposes, such as water supply. At nearly all these cities some water power is used for manufacturing, but all the large establishments depend to a certain extent on the use of steam power.

Municipal supplies.—The municipal water supplies for all the cities along Rock River are obtained from wells, most of them from 1,000 to 2,000 feet deep. Analyses by the State Water Survey of samples of water from these wells show the mineral content to be much the same as that of the river water. These well waters are free from the turbidity and sewage pollution of the river water, so that the only reason for changing from the underground to surface supply would be an insufficient supply of the former. As the cities along the river increase in population and in manufacturing establishments the time may come when the underground supplies will not be sufficient. In such cases the river water can be so purified as to make an acceptable supply.

Samples.—To determine the quality of water in Rock River samples were obtained at Rockford and Sterling, the largest cities on the river in Illinois. At each place a 4-ounce bottle was filled with river

[a] Census of Manufacture, 1905, Illinois; Bull. U. S. Bureau Census, No. 52.

water and mailed to the laboratory of the Illinois State Water Survey at Urbana every day for a year, beginning August 1, 1906. Samples of the river water at Rockford were furnished by Fred H. Gregory, chief engineer of the waterworks. The waterworks pumping station is located on the river bank; and the daily samples were collected from the circulating pump that furnishes water for the condensers.

The samples of water at Sterling were collected by C. A. Yohn, chief engineer of the Illinois Straw Products Company, of Rock Falls. The plant of this company is run partly on water power, but some steam power is used at all times, as the water power is not sufficient. The sample bottles were filled from a pump taking water from the river just outside the wheelhouse. Owing to the breakage and loss of bottles in the mails and to accidents in the laboratory, several analyses were not completed or seemed too irregular for use. The analyses completed in a satisfactory manner are given in Tables 23 and 24, together with average values for the year.

Quality of water.—For the sake of comparison with one another and with analyses from other rivers, the average analyses for the year at Rockford and Sterling are given in Table 3 in the form used by Clarke.[a] This form of expression shows the percentage composition of the dry residue from the evaporation of filtered water from the river.

TABLE 3.—*Average percentage composition of dry residue from filtered Rock River water, August 1, 1906, to July 31, 1907.*

	Rockford.	Sterling.
Carbonate (CO_3)	49.6	48.4
Sulphate (SO_4)	8.8	9.4
Chlorine (Cl)	1.8	2.1
Nitrate (NO_3)	1.6	1.4
Calcium (Ca)	18.0	18.3
Magnesium (Mg)	10.0	10.1
Sodium and potassium (Na+K)	4.0	4.5
Silica (SiO_2)	6.0	5.6
Iron oxide (Fe_2O_3)	.2	.2
	100.0	100.0
Salinity, parts per million	250	267

These analyses show that the composition and amount of dissolved mineral matter are much the same at the two cities 60 miles apart. As is usually the case where a river flows through a populated region with manufacturing cities, the amounts of sodium, chlorine, and sulphate increase, as does the total amount of dissolved material. The most striking difference in the water at the two places is in the turbidity and suspended matter, the values for which are twice as great at the lower station as at the upper one. The greatest variation between different samples from the same station are in the turbidity and suspended matter. Rivers in general grow more turbid toward their

[a] Clarke, F. W., The data of geochemistry: Bull. U. S. Geol. Survey No. 330, 1908.

mouths, but at any place the turbidity may be due to local causes and not really represent the general condition of the river. If the figures for the average analysis for either Rockford or Sterling were taken to represent the average quality of the water at any point along the river in Illinois, the error would hardly amount to 10 per cent, which for any industrial purposes might be neglected.

To show the connection between the stage of the river and the quality of the water, use has been made of the discharges calculated from the United States Geological Survey gage heights. Although the distance by river from Rockton to Rockford, where the water samples were collected, is about 13 miles, the discharge at Rockford is probably not very different from that at Rockton. In order to study the variations in amount of mineral matter carried past Rockford in solution, the amount in tons per twenty-four hours has been calculated for each ten-day period. These values are given in Table 4.

TABLE 4.—*Discharge of and dissolved solids in Rock River at Rockford.*

Date.	Discharge (second-feet).[a]	Dissolved solids.	
		Parts per million.	Tons per 24 hours.
1906.			
October 1–October 8	638	243	418
October 10–October 18	532	296	485
October 20–October 29	711	281	540
November 1–November 8	847	286	652
November 10–November 19	712	287	550
November 20–November 29	1,990	274	1,470
December 1–December 10	2,329	256	1,610
December 11–December 20	1,603	295	1,270
December 21–December 31	1,451	320	1,250
1907.			
January 1–January 10	6,401	218	3,760
January 11–January 20	5,839	228	3,590
January 21–January 30	12,200	173	5,680
February 10–February 18	5,970	261	4,610
February 19–February 28	6,561	194	3,430
March 2–March 10	3,590	233	2,250
March 11–March 20	4,427	230	2,750
March 21–March 31	5,716	243	3,750
April 1–April 10	9,433	223	5,660
April 11–April 20	7,648	246	5,070
April 21–April 30	5,136	266	3,680
May 1–May 10	4,630	275	3,430
May 11–May 20	2,941	306	2,430
May 21–May 31	4,303	268	3,250
June 2–June 10	5,613	268	4,050
June 11–June 20	6,029	275	4,470
June 21–June 30	4,075	283	3,110
July 1–July 10	4,202	243	2,750
July 11–July 20	5,278	239	3,400
July 21–July 31	7,655	247	5,030
Average	4,430	257	2,910

[a] Calculated from measurements made at Rockton.

The average discharge at Rockford for the period from October 1, 1906, to July 31, 1907, was 4,430 cubic feet per second. The average discharge at Rockton, calculated from observations of the United States Geological Survey for a number of years, is 4,900 cubic feet per second. The average discharge at Sterling, calculated

in the same manner, is 6,600 cubic feet per second. The average amount of dissolved mineral matter carried past Rockford from October 1, 1906, to July 31, 1907, was 2,910 tons per twenty-four hours. The amount of dissolved matter carried past Rockford annually, calculated from the figures for the average flow throughout a year and the average value of the dissolved matter for a year, as given in Table 4, is 3,300 tons per twenty-four hours, and the amount carried past Sterling is 4,760 tons per twenty-four hours. The average amount of suspended matter varies more than the dissolved matter. It is probable that the variation in amount of suspended matter is not uniform throughout the river but is largely dependent on local conditions.

The amount of dissolved matter in parts per million is the least variable of the three quantities given in Table 4. This shows, as might be expected, that during times of high water the river has a smaller amount of dissolved mineral matter in a given amount of water. This reduction is not proportional to the increase in the flow, because an increase in flow above the normal is not caused wholly by water free from mineral matter. In times of high flow much of the water in the river has not been on or in the ground for any considerable time, and therefore has not dissolved much mineral matter. Nevertheless it is not pure rain water.

Consideration of the amounts of dissolved solids and the discharges for the different periods at the two stations show that these quantities are both more variable at Rockford than at Sterling. It is characteristic of normal rivers to be more variable in flow and in quantity of water near their sources than farther downstream, where the larger number of tributaries tend to equalize the flow and quality of the water.

Summary.—The water of Rock River is a good average water for Illinois. It is not safe for drinking, but could be made so. The turbidity is of such a nature as to be easily removed by moderate storage, leaving a clear water. The magnesium is high, but the magnesium and calcium are present almost wholly as carbonate or bicarbonate, so that the softening of the water for laundry purposes is a simple matter. The water forms little scale when used in steam boilers; washing out once a week with a good stream of water will keep most boilers free from it. All these things and more might also be said for the well waters in the Rock River valley, but the well waters can not be obtained in great abundance by merely running a few feet of pipe out from a pump, as those of the river can be. The easily available supply of satisfactory industrial water from the river will be a large factor in saving the more potable underground water and in increasing the amount of manufacturing carried on in the cities located on the river.

ILLINOIS RIVER DRAINAGE BASIN.

GENERAL STATEMENT.

Illinois River drains nearly one-half the State. The direct drainage into the river is small, nearly all of its flow coming from large tributaries. The tributaries and their drainage areas are given in the following list:

Area of drainage basins of tributaries of Illinois River.[a]

	Square miles.		Square miles.
Desplaines River	1,392	Sangamon River	5,670
Kankakee River	5,146	Crooked Creek	1,385
Fox River	2,700	Macoupin Creek	985
Vermilion River	1,317	Smaller tributaries	6,232
Mackinaw River	1,217		27,914
Spoon River	1,870		

CHICAGO DRAINAGE CANAL.

Since the compilation of Cooley's report the apparent area of the Illinois River drainage basin has been increased by about 6,000 square miles. This is the area which, under normal conditions in Illinois, would furnish the amount of water which reaches Illinois River through the Chicago drainage canal. Thus it is evident that the drainage canal is one of the largest tributaries of Illinois River.

Owing to the fact that the drainage canal furnishes water from Lake Michigan, with a considerable amount of added material from the Chicago sewage, it exerts an effect on the quality of the water which is more than proportional to its drainage area. With this added material, the total dissolved mineral matter in the water of the drainage canal was found by Palmer to be about 163 parts per million, this value being obtained as the average of a number of analyses made on samples collected about every other day for a period of three months after the opening of the drainage canal. Although this is considerably more than the 133 parts per million usually found in Lake Michigan water, it is very much lower than the average for the other tributaries of the Illinois which have been examined in this work, the average solids in each of these other tributaries being over 250 parts per million. In connection with the analyses made at Peoria, the effect of the drainage canal on the character of the water can be more clearly shown. It was proved to the satisfaction of the courts that the canal exercised no injurious effect upon the quality of Mississippi River water at St. Louis. On the other hand, it was shown that the quality of the water in Illinois River is improved throughout almost all of its course by the addition of the Lake Michigan water, even with the Chicago sewage it carried.

[a] Cooley, L. E., 1889. The Illinois River basin in its relation to sanitary engineering, Illinois State Board of Health.

DESPLAINES RIVER.

Drainage.—Illinois River is formed by the union of Desplaines and Kankakee rivers. Desplaines River rises in Kenosha County, Wis., and flows southward about as far as Chicago, where it turns to the southwest, continuing in this direction till it joins the Kankakee. The length of the river is about 90 miles. It drains a narrow strip of land parallel to Lake Michigan, with an area of 1,392 square miles.

Municipal supplies.—The cities along the Desplaines River obtain their water supply from deep wells, except that Joliet derives part of its supply from Hickory Creek. It is not likely that the water from Desplaines River can ever be used for municipal supply, except in its upper course.

From a point below Chicago the Desplaines is paralleled by the old Illinois and Michigan canal and the new Chicago drainage canal. The Illinois-Michigan canal has always carried a large volume of Chicago sewage. Power from this canal is used at many places by allowing the water to flow from the canal to the river, thus contaminating the river water. At Lockport the Chicago drainage canal enters Desplaines River, and as the flow of the drainage canal is often larger than the other flow of the river, the character of the river water at Joliet is that of a diluted sewage.

Quality of water.—In the preparation of this report no samples were taken from Desplaines River. From the likeness between the waters of Fox and Rock rivers, which drain the same geologic formations as those drained by Desplaines River, it is probable that the water of the Desplaines is very similar to that found in the Fox and Rock, in which calcium and magnesium carbonates are the chief constituents of the dissolved mineral matter. The water of the Desplaines should be fairly satisfactory for industrial uses where cleanliness is not a requisite. There is considerable turbidity throughout the course of the river, and after it has received contamination from the Chicago sewage it contains a large amount of offensive organic matter which would make it of no value for many industrial purposes.

KANKAKEE RIVER.

Drainage.—Kankakee River is, next to the drainage canal, the largest component of the upper Illinois River. It drains an area of 3,200 square miles in its 85 miles of length in Indiana. The remainder of its 140 miles of length and 5,300 square miles of drainage area are in northern Illinois.[a] The ordinary low-water discharge is given in the Tenth Census as 1,300 cubic feet per second. A large portion of the area drained in Indiana and some of the area drained in Illinois is swamp land. This has a tendency to make the discharge more uni-

[a] Greenleaf, J. L., Water power of the Mississippi River and some of its tributaries: Tenth Census, 1887, p. 130.

form and, as a consequence, to produce greater uniformity in the amount and character of the dissolved mineral matter.

Municipal supplies.—The largest city on the river is Kankakee, where filtered river water is used for the municipal supply. The city of Wilmington also obtains its supply of water from the river. Momence, Bradley, and the smaller cities along the river find a sufficient amount of water in wells in the limestone or in the glacial drift. The manufacturing carried on in the cities along Kankakee River is of such a nature that the quality of the river water is not much affected by it. Sewage is discharged into the river by the various cities, making necessary some sort of purification before the water can be considered safe for domestic use.

Samples.—Through the kindness of Mr. C. H. Cobb, superintendent of waterworks at Kankakee, arrangements were made for the daily collection of samples from Kankakee River. During the first part of the period covered by this report samples were obtained by dipping them from the river, but after February 19, 1907, samples were taken from the pump which draws water from the river for the waterworks. These samples from the pump were collected and mailed by Mr. A. L. Straley. The analyses of composite samples, together with the average for the year, are given in Table 25.

Quality of water.—In the section of Indiana drained by Kankakee River are extensive beds of marl that is very nearly pure calcium carbonate. The surface rock in the northern part of Indiana and the portion of Illinois drained by the Kankakee is more nearly a pure limestone than the magnesian limestone in the areas drained by Rock, Fox, and Desplaines rivers. This character of the rock affects the composition of the water, as may be seen by comparison of the average analyses of Rock and Fox rivers with the average of Kankakee River. At the four stations on Rock and Fox rivers the average percentage of magnesium is 10.1, and the average ratio of magnesium to calcium is nearly 0.6. At Kankakee the magnesium is only 7.5 per cent of the total dissolved solids and is less than 0.4 of the calcium. The Kankakee water contains a larger percentage of sulphate than most of the Illinois waters. This constituent makes it a less desirable water for boiler purposes, as it is more liable to form a hard scale.

The comparative uniformity in amount of dissolved material in the river water is shown by the fact that the average difference between the values for total solids and the mean value is only 6.4 per cent of the mean value, whereas the average difference for the other rivers of the State is 11 per cent of the mean value. Owing probably to the storage in swamps and the consequent slow delivery to the river, the turbidity and suspended matter at Kankakee are very much less than are found in most of the other rivers of the State. This lower turbidity makes the water simpler to treat when it is to be purified for domestic use.

FOX RIVER.

Drainage.—Fox River rises in Wisconsin, northwest of Milwaukee and flows southward and then southwestward into Illinois, joining Illinois River at Ottawa, 35 miles below the mouth of Kankakee River. The region drained by Fox River is almost entirely covered with glacial drift containing much magnesian limestone. The total area of the drainage basin is about 2,500 square miles, all but a small portion of which is in Illinois. Several lakes in Wisconsin, of which Geneva and Fox lakes are the largest, discharge into the river. They regulate its discharge to a certain extent, but not enough to keep it from being highly variable in Illinois.

Water power.—The Fox has less fall in Wisconsin than in Illinois. In the last 47 miles of its course there is a fall of 136 feet, and in the 5 miles above Ottawa, where it enters the Illinois, the average fall is 6 feet to the mile. There is, therefore, a large amount of water power available along the river, much of which is utilized. The feeder from a point above Dayton to the Illinois and Michigan canal at times takes almost the whole flow of the river, and on this account power from the river can not be utilized below this point. Several cities are located at power sites along the river, though the water power now in use is very little compared with the amount of steam power used in the factories of the larger cities.

Municipal supplies.—Elgin is probably the most widely known of the cities on Fox River. Besides the manufacture of watches and watch cases, there are here several plants that turn out cooperage, foundry, and machine-shop products. A large amount of general manufacturing is carried on at Aurora. The leading industry is the manufacture and repair of cars and other railroad rolling stock.

The greater part of the water used in manufacturing along Fox River is used in the production of power, largely in steam engines. For the production of steam and for condenser use the river water is as good as any other supply that can be as easily obtained. It is also abundant. The industrial establishments discharge into the river very little material which has any noticeable effect on the character of the water.

Part of the city water supply of Elgin is taken from Fox River, the rest of it being obtained from deep wells. Analyses by the Illinois State Water Survey indicate that the well water is somewhat better in quality than the average river water.

Elgin is about the lowest town on the stream which could use the river water as a source of municipal supply. All the cities below Elgin discharge sewage into the river, making it difficult to purify the water sufficiently for domestic use. Fortunately, throughout the course of the river there is an abundant supply of water in deep rock and in the glacial drift.

Samples.—Samples from which analyses were made for this report were obtained through the kindness of Mr. R. R. Parkins, chief engineer of the Elgin waterworks. Samples were collected daily from the pump drawing water from the river for the filter plant. Analyses of the composite samples of the water from Elgin are given in Table 26.

At Ottawa, near the junction of Fox and Illinois rivers, samples were collected from Fox River daily from August 1, 1906, to July 31, 1907. These samples were taken by Mr. M. P. Lannigan, pumper for the Rock Island Railroad. The samples were collected from the pump at the watering station of the railroad. Analyses of the composite samples obtained at Ottawa are given in Table 27.

Quality of water.—Estimates made from figures by Cooley give the average discharge of Fox River at Elgin as 1,100 cubic feet per second. This value makes a discharge at Elgin of 860 tons of dissolved mineral matter and 68 tons of suspended matter per twenty-four hours. As calculated from Cooley's figures, the average discharge at Ottawa is 1,900 cubic feet per second. This gives a value of 1,720 tons of dissolved mineral matter and 450 tons of suspended matter carried at Ottawa each twenty-four hours. For the sake of comparison, the percentage composition of the average residue from the evaporation of filtered river water at Elgin and Ottawa is given in Table 5.

TABLE 5.—*Percentage composition of residue of Fox River water at Elgin and Ottawa.*

	Elgin.	Ottawa.
Carbonate (CO_3)	46.8	41.4
Sulphate (SO_4)	13.5	18.7
Chlorine (Cl)	1.8	2.4
Nitrate (NO_3)	.9	1.5
Calcium (Ca)	18.1	18.4
Magnesium (Mg)	10.6	9.8
Sodium and potassium (Na+K)	3.9	4.3
Iron oxide (Fe^2O_3)	.1	.1
Silica (SiO_2)	4.3	3.4
	100.0	100.0
Salinity, parts per million	282	326

The percentage composition shows that the character of the water at Elgin and Ottawa is very much the same, the differences being such as usually occur in a river passing through an inhabited region containing cities of considerable size. The percentages of sulphate, chlorine, and sodium are slightly increased and the percentage of carbonate is decreased at the lower point. The salinity—that is, the amount of mineral matter dissolved in the water—is decidedly increased. As may be seen by comparison of Tables 26 and 27, the turbidity and suspended matter are very much greater at Ottawa than at Elgin. Even with this increase, however, Fox River at Ottawa is usually a fairly clear stream. The suspended matter of

Fox River water is not difficult to remove, so that filtration of the water would not be attended by any special difficulties. The water at Ottawa is not so variable in character as that at Elgin. The average difference between the mean value for dissolved solids and the individual values is 8.2 per cent of the mean value at Elgin; at Ottawa it is only 7.3 per cent. The difference between the maximum and the minimum values for dissolved solids at Elgin is 50 per cent of the mean value; the difference at Ottawa is 42 per cent. This greater uniformity in the character of the water downstream is characteristic of most rivers.

As mentioned above, the drainage basin of Fox River contains a large amount of glacial drift made up very largely of magnesium-bearing limestones. This characteristic of the soil and subsoil is shown in the character of the water. Except Rock River, none of the rivers examined has so large a percentage of magnesium as Fox River. The proportion of magnesium to calcium is about the same for Fox and Rock rivers, but the percentage of sulphate in the Fox is larger than in the Rock. This, together with the larger amount of dissolved mineral matter, would make the water of Fox River less desirable than that of Rock River for many purposes. The difference between them, however, is not very great. To soften Fox River water and make it perfectly satisfactory for boiler use and for use in laundries would require only a small amount of comparatively inexpensive chemicals.

VERMILION RIVER.[a]

Drainage.—Vermilion River rises in the Bloomington morainic system, at the reentrant angle in southeastern Livingston and western Ford counties,[b] and flows in a northwesterly direction till it meets the Illinois at Lasalle. The drainage area is about 1,410 square miles. The country is fertile and well cultivated. The slope of the river is very moderate and the flow is exceedingly irregular. It is said that at times there is less flow at the mouth than at Pontiac, 20 miles up the river.

Municipal supplies.—Pontiac and Streator both obtain their municipal supplies from the river. In each place the water is treated with coagulant and filtered. At times of low water the whole flow of the river is utilized at Streator.

Samples.—For this report samples were collected through the kindness of Mr. R. D. Huggans, superintendent of the Streator Aqueduct Company. During the first part of the period samples were taken directly from the intake pump. Later a screen was put in over the mouth of the intake pipe for the sake of lessening the turbidity of

[a] Not to be confused with the Vermilion River that empties into Wabash River.

[b] Leverett, Frank, The Illinois glacial lobe: Mon. U. S. Geol. Survey, vol. 38, 1889.

the water as delivered to the filters, and after this daily samples were dipped up directly from the river. The analyses made of the composite samples from Streator are given in Table 28.

Quality of water.—The quality of the water at Streator varies more than the water of average streams in Illinois. The amount of dissolved mineral matter is also higher than in most of the rivers. Like that of the other rivers in the northern part of the State, the water contains a large amount of magnesium. The value for the sulphate is also higher at Streator than at any of the other stations in the northern part of the State. The water of Vermilion River is not so satisfactory for domestic or industrial use as that of many other streams in Illinois.

SANGAMON RIVER.

Drainage.—Sangamon River rises in the Bloomington morainic system in eastern McLean County. It drains an area of 5,670 square miles, which is mainly rolling prairie. In the first 10 miles the river has a fall of 120 feet and in the remaining 170 miles of its length a fall of 300 feet. This fall is unevenly distributed, the river having many stretches of almost still water and other stretches of rapid flow. On account of the variability of the flow and the fact that through most of the course of the river its bed is in gravel and sand, there is almost no water power developed.

Municipal supplies.—Springfield is the largest city on Sangamon River. The population of Decatur, the next in size, is only two-thirds that of Springfield, but the value of articles manufactured at Decatur in 1904 was over a third greater than the value of those manufactured at Springfield. None of the leading industries in either city is largely dependent on water for any purpose except the generation of power. The effect on the river of wastes from the factories is negligible as compared with the effect of the sewage from all the cities along the river. The municipal water supplies of Decatur and Springfield are obtained from the river. At Decatur the water is impounded by a dam, treated with a coagulant, and filtered. At Springfield part of the supply is pumped directly from the river and the remainder is obtained from filter galleries near the river.

The turbidity of Sangamon River is usually somewhat high at all points. This turbidity is not difficult to remove, and at Decatur the water is treated and furnishes a very satisfactory supply. At Springfield, where it has been used without treatment, it is not very inviting to drink nor cleansing when used for washing. Like most Illinois river waters, that of the Sangamon contains enough salts of calcium and magnesium to form a considerable amount of scale when used in boilers and to make it unsatisfactory for laundry purposes. It is not likely, however, to form much hard scale in boilers if they are prop-

erly cared for, and the expense of treating it so as to make it suitable for laundry purposes is not very great.

Samples.—For the preparation of this report samples of water were collected at Decatur, Springfield, and Chandlerville. The collections at Decatur were made by Mr. Fred Litterer, chief engineer of the city waterworks; those at Springfield by Mr. Gus Obert, chief engineer of the city waterworks; and those at Chandlerville from the river at the crossing of the highway bridge, northeast of town, by Messrs. J. W. Martin and John Madden and Miss Bessie Long. The bottles were filled by dipping the water from the stream and pouring into the bottles, until April 20, 1907, after which time the bottles were let down with a sinker and filled under the surface. Many collections were omitted at both Springfield and Chandlerville. It was difficult to determine the reasons for the omissions at Springfield. The omissions at Chandlerville were due in part to high water, which at one time covered the bridge from which samples were usually collected. Other omissions were due to illness of one of the collectors.

Quality of water.—Analyses of the composite samples from Decatur, Springfield, and Chandlerville are given in Tables 29, 30, and 31, together with averages for the year. The percentage composition of the dry residue from river water at these three points is given in Table 6.

TABLE 6.—*Percentage composition of dry residue from Sangamon River water.*

	Decatur.	Springfield.	Chandlerville.
Carbonate (CO_3)	44.7	43.7	44.4
Sulphate (SO_4)	11.9	13.3	12.7
Chlorine (Cl)	1.8	2.7	2.7
Nitrate (NO_3)	2.9	1.2	2.2
Calcium (Ca)	18.7	18.7	18.4
Magnesium (Mg)	8.8	8.6	8.8
Sodium and potassium (Na+K)	4.7	5.8	5.3
Iron oxide (Fe_2O_3)	.1	.2	.2
Silica (SiO_2)	6.4	5.8	5.3
Salinity, parts per million	295	278	282

This shows that the water for the year is much the same throughout the length of the river. The dissolved mineral matter in Sangamon River is not very different in character from that in the other tributaries of the Illinois. The Sangamon water resembles the water of the northern tributaries more than that of the Kankakee. Owing in part to the fact that the Sangamon receives a number of large tributaries along its course, there is no particular relation between the samples at the different points of collection. The analyses at Decatur are probably of more value than those from Springfield and Chandlerville.

ILLINOIS RIVER.

Samples.—On Illinois River itself daily collections of water were made at Lasalle, Peoria, and Kampsville. At Lasalle collections were made by Mr. James Brotherton at the Illinois Central pumping station. This pumping station is south of the city, at the point where the Illinois Central Railroad crosses the river, and is above the point of discharge of the Lasalle sewage. It is probable that at this locality the water of various tributaries is well mixed. The stream at Lasalle is made up of water from Desplaines, Kankakee, Fox, Vermilion, and Little Vermilion rivers, together with the flow from the Chicago drainage canal.

From Lasalle to Peoria no tributaries of any considerable size enter the river. In consequence, the quality of the water at Peoria is not very different from that at Lasalle. At Peoria samples were collected from the bridge across the river near the Peoria waterworks by Mr. Alfred Barton in bottles let down with a sinker and filled under the surface.

Between Peoria and Kampsville a number of tributaries enter the river. The largest of these is the Sangamon, the average discharge of which is about one-fifth of the discharge of the Illinois at Kampsville. The other tributaries entering between Peoria and Kampsville are Mackinaw River, Spoon River, and Crooked Creek. Collections at Kampsville were made by Mr. Ira Davidson, samples being obtained by dipping the water from the surface of the river midway across the stream. This method of collecting is subject to errors which have been previously discussed.

Quality of water.—The analyses of composite samples made from the daily samples at Lasalle, Peoria, and Kampsville are given in Tables 32, 33, and 34, together with average values for the year. The percentage composition of the dry residue from the filtered water at each of these stations is given in Table 7.

TABLE 7.—*Percentage composition of dry residue from filtered Illinois River water.*

	Lasalle.	Peoria.	Kampsville.
Carbonate (CO_3)	37.0	36.7	38.5
Sulphate (SO_4)	18.6	18.1	16.3
Chlorine (Cl)	4.8	4.9	5.8
Nitrate (NO_3)	2.4	2.9	1.7
Calcium (Ca)	18.6	18.5	18.2
Magnesium (Mg)	8.1	7.9	7.8
Sodium and potassium (Na+K)	5.9	6.4	7.0
Iron oxide (Fe_2O_3)	.1	.1	.1
Silica (SiO_2)	4.5	4.5	4.6
	100.0	100.0	100.0
Salinity, parts per million	270	265	258

When these results are all taken together, it is evident, as would be expected, that the water at Lasalle and Peoria is almost the same; though the suspended matter is less at Peoria, probably owing to the facts that the river at Peoria has a very sluggish flow and that at the middle of Peoria Lake where the samples were collected opportunity had been afforded for the settling of the suspended matter.

Illinois River water is not so high in carbonates as other waters of the State, and is higher in sulphates. It also has a larger percentage of chlorine than the average waters in the State. This increase in sulphates and chlorine is probably due largely to the effect of Chicago sewage, as the tributaries above Lasalle have much lower percentages of chlorine. The variation in quality of the water is much less in the upper Illinois than in other streams in the State. At Kampsville the average variation in dissolved solids is 10 per cent of the mean value, and the range from maximum to minimum is 65 per cent of the mean value. As before stated, this is probably due in part to the method of collecting the samples. As the samples are taken just above the dam, it is possible that a high rainfall with quick run-off in the immediate vicinity of the point of collection would cause a dilution of the upper layer of water which would be much greater than the dilution of the whole flow of the stream. The widest difference from the average value of the dissolved solids is in one sample where the value was very low at a time of high turbidity.

Discharge.—The discharge of Illinois River at Lasalle has been measured at various times and gage readings have been taken by different branches of the government service. During the period covered by this report gage heights have been read by the Weather Bureau. From these readings and from the rating table prepared from a few discharge measurements made by the United States Geological Survey in 1903, discharge measurements have been calculated for each of the days when collections were made. Owing to the fact that the relation between the Weather Bureau gage and the United States Geological Survey gage had to be determined by reference to Chicago datum and Memphis datum, with various corrections to be applied, the discharge measurements are probably not as accurate as those at Peoria, where the United States Geological Survey was maintaining a gage during the course of the analytical work.

The discharge measurements computed from measurements at Lasalle, together with the dissolved solids for each ten-day period, are given in Table 8, which shows also the amount of dissolved material carried by the river each twenty-four hours. The average variation in the discharge at Lasalle is 30 per cent of the mean value for the discharge. The average variation in the solids is 6.9 per cent of

the average value. The average variation in the dissolved material carried by the river is 33 per cent of the mean value.

TABLE 8.—*Discharge of and dissolved solids in Illinois River at Lasalle.*

Date.	Discharge (second-feet).	Dissolved solids.	
		Parts per million.	Tons per day.
1906.			
August 1–August 10	7,100	265	5,070
August 11–August 20	7,160	262	5,060
August 21–August 30	7,580	252	5,150
August 31–September 9	7,560	235	4,790
September 10–September 19	7,150	221	4,260
September 20–September 29	7,190	241	4,670
September 30–October 7	7,860	284	6,020
October 10–October 19	7,350	260	5,160
October 20–October 28	7,410	268	5,350
October 30–November 8	7,400	275	5,480
November 9–November 19	7,360	276	5,470
November 20–November 30	9,950	300	8,060
December 1–December 10	11,900	320	10,280
December 11–December 20	13,430	284	10,290
December 21–December 31	12,580	311	10,560
1907.			
January 1–January 10	15,970	296	12,740
January 11–January 20	21,500	298	17,280
February 1–February 9	25,280	289	19,700
February 10–February 18	20,140	311	16,880
February 19–February 28	18,370	273	13,520
March 1–March 10	12,970	274	9,590
March 11–March 20	14,960	257	10,380
March 21–March 28	14,860	272	10,910
April 2–April 10	19,360	299	15,610
April 11–April 20	14,900	344	13,820
April 21–April 30	11,640	266	8,360
May 1–May 10	14,990	272	10,990
May 11–May 20	12,650	300	10,250
May 21–May 31	14,730	279	11,080
June 1–June 10	15,390	307	12,740
June 11–June 20	14,350	276	10,680
June 21–June 30	12,210	276	9,100
July 1–July 10	11,160	256	7,700
July 11–July 20	19,650	255	13,500
July 23–July 31	14,550	288	11,400
Average	12,820	278	9,770

The discharge of the river at Peoria has been carefully measured for a long series of years. During the period covered by this report daily gage readings were made by an observer of the United States Geological Survey. A rating table for the river at Peoria has been prepared to cover this period. From this rating table and the gage measurements the discharge of the river at Peoria has been calculated for each day when samples were collected. These have been averaged into ten-day periods corresponding to the composite samples. From the average discharge in second-feet and the value in parts per million of the dissolved solids, as determined by evaporation of the filtered water, the amount of dissolved material carried past the gaging station at Peoria by the water of Illinois River each twenty-four hours has been calculated. The figures are given in Table 9, together with the average values. The average variation in discharge at Peoria was 35 per cent of the mean value of the dis-

charge. The average variation of the dissolved solids was 6.3 per cent of the mean value. The average variation in the amount of material carried by the river was 36 per cent of the mean value.

TABLE 9.—*Discharge of and dissolved solids in Illinois River at Peoria.*

Date.	Discharge (second-feet).	Dissolved solids.	
		Parts per million.	Tons per 24 hours.
1906.			
August 1–August 9	6,820	266	4,880
August 31–September 9	8,180	245	5,390
September 10–September 19	7,470	260	5,220
September 20–September 29	7,110	222	4,260
September 30–October 9	8,300	249	5,580
October 10–October 19	7,990	279	6,000
October 20–October 29	7,680	233	4,780
October 30–November 8	7,770	264	5,510
November 9–November 19	7,720	250	5,200
November 20–November 30	9,420	259	6,580
December 1–December 10	12,160	310	10,180
December 11–December 20	15,270	293	12,060
December 21–December 31	14,210	294	11,280
1907.			
January 1–January 10	15,760	310	13,150
January 11–January 20	23,120	309	19,260
January 21–January 31	44,620	223	26,800
February 1–February 9	33,130	242	21,600
February 10–February 18	23,050	275	17,070
February 19–February 28	20,110	275	14,900
March 1–March 10	18,140	279	14,130
March 11–March 20	18,000	275	13,800
March 21–March 31	20,270	272	14,830
April 1–April 10	24,570	272	17,250
April 11–April 20	21,510	304	17,650
April 21–April 30	17,210	271	12,580
May 1–May 10	17,700	276	12,900
May 11–May 20	21,510	289	16,750
May 21–May 30	17,210	283	13,100
June 1–June 10	20,430	277	15,250
June 11–June 20	19,950	290	15,600
June 21–June 30	17,890	272	13,100
July 1–July 10	15,460	270	11,250
July 11–July 20	22,530	257	15,620
July 21–July 31	22,480	257	15,560
Average	16,900	271	12,330

Variation in quality.—In the flow of an ordinary river it is usual to expect the lowest value for the dissolved solids, the highest value for the suspended solids, and the highest value for the discharge to come at about the same time. In times of low water the river is fed largely by springs or by water which reaches the river through infiltration from the sides and through the bed. This ground water is naturally clear, and by reason of its passage through the ground has dissolved a considerable amount of mineral matter. In times of storm a large proportion of the water which falls drains immediately into the river. As it runs quickly over the surface of the ground it picks up loose material, so that upon entering the stream it carries a large load of suspended matter, while it has had time to dissolve very little. This makes the water of the stream high in turbidity and low in dissolved solids. On this account one would expect that the amount of dissolved material carried by a given point in a river

would be much less variable than the discharge of the river. If, in time of flood, the discharge of the river is five times the low-water discharge, the amount of dissolved material carried by the river will rarely be five times as great. On the other hand, the volume of four times the low-water flow which has been added to the low-water flow is not pure water. Therefore the amount of dissolved material carried by the river will be very much greater than the amount carried in low water. Rock River at Rockford (see p. 23) is an illustration of a normal river.

Illinois River at Lasalle and Peoria shows very decidedly the effect of the Chicago drainage canal in maintaining the uniformity of quality of water. Although the values for the average variation in discharge at these two points are 30 and 35 per cent, respectively, the variations in amount of material carried are 33 and 36 per cent. This indicates that the water of Illinois River in time of flood has a tendency to carry more dissolved material than at times of low flow. This results from the fact that nearly one-half of the low-water flow of Illinois River at Lasalle and Peoria is furnished by the Chicago drainage canal, which contains on the average about 160 parts per million of dissolved solids. This, combined with an equal volume of low-water flow from Desplaines, Fox, Kankakee, and Vermilion rivers, gives a resulting water which is still low in dissolved solids, although the other tributaries carry probably over 300 parts per million. The average amounts of dissolved solids carried by three of these rivers are as follows: Fox, 335 parts per million; Kankakee, 288 parts; Vermilion, 325 parts. It is probable that the natural water of the Desplaines carries about the same amount of dissolved solids as the other tributaries. Even the high-water flow of these tributaries carries much more dissolved solids than the Chicago drainage canal. Thus it comes about that in many cases a rise in the river is accompanied by an increase in the proportion of dissolved solids, which makes the amount of material carried past a given point increase faster than the discharge.

These results at Peoria and Lasalle show one benefit of the Chicago drainage canal, which has possibly been overlooked in considering the many changes which have resulted from its opening. One of the objections to the use of river water for industrial purposes or for a municipal supply, where it is necessary to treat the water, is that the variation in character of the water from day to day and from season to season is so great that any treatment of the water based on the results of only a few examinations is liable to be unsatisfactory for a great part of the time. Any change in quality of the water will require a change in treatment, and some river waters are so variable in quality that it would be useless to attempt to treat them without expert chemical supervision; it would be necessary to test the water

each day and apply the chemicals in amounts determined by these tests. For a uniform water, such as a deep-well water or many ground waters, a single analysis suffices to determine the kind of treatment and the amount of each chemical necessary to add, thus making it possible to handle a water-purification plant with much less expense for supervision. A river water as constant in character as the Illinois at Peoria and Lasalle, however, might be given an average treatment—that is, a treatment based on the results of an average analysis, such as are given in this report. This treatment would probably be better than a varying treatment determined from day to day by a person not very skilled in chemical manipulation.

Municipal supplies.—Illinois River water is not used for municipal supply, but a very large amount of it is used by various manufacturing establishments along the river. Practically all the cities on the river are able to obtain a supply of underground water which has almost the same mineral content as the river water and at the same time is free from pollution. It is doubtful if the time will ever come when Illinois River water will be looked upon with favor as a source of municipal supply. The large amount of sewage in the Chicago drainage canal would make people hesitate to undertake the purification of the water. As was shown in the investigations in connection with the lawsuit over the drainage canal,[a] a large amount of organic matter enters the river at Lasalle, Peoria, and Pekin—more, at the time of Palmer's investigations, than that entering through the Chicago drainage canal. It is possible that in the lower part of the river the water might be used safely for municipal supply, provided it were properly purified.

KASKASKIA RIVER.

Drainage.—Kaskaskia River rises in the Champaign morainic system, immediately west of Champaign, gradually descends from an elevation of 730 feet to 542 feet, and enters the Mississippi above Chester in Randolph County. About 590 square miles of comparatively level area are drained by the river in its length of 180 miles.[b]

Because of its variations in flow Kaskaskia River has never been used to any great extent as a source of power. At Carlyle, during the year covered by this report, there was a rise of 23 feet in the river. In the summer time it often runs nearly dry in some parts of its course. A careful survey has been made by the Illinois State Geological Survey, with the object of determining a method of treatment of the Kaskaskia River bottoms so as to reclaim a large amount of land which is now flooded so frequently as to render it practically useless for agricultural purposes. If this land is reclaimed, the discharge of the river will be more variable than at present.

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[a] Palmer, A. W., Chemical survey of the waters of Illinois, University of Illinois, 1902.
[b] Leverett, Frank, The Illinois glacial lobe: Mon. U. S. Geol. Survey, vol. 38, 1889.

Municipal supplies.—Vandalia and Carlyle are supplied with water from Kaskaskia River. Shelbyville formerly obtained its supply from the river, but now takes water from wells in the gravel near the river. This water, intercepted on its way to the river, has much the same character as that of the river and is free from turbidity. In the river water at Shelbyville the turbidity averaged over 100 parts per million during the year covered by this report.

Samples.—Daily samples were collected from the river at Shelbyville by Mr. Isaac Nutt, engineer of the Shelbyville Water Company, by dipping water from the river at a point directly opposite the waterworks. An old dam, partly destroyed, crosses the river at this point, and the water was dipped from a broken place in this dam, through which the stream flows rapidly. Through the kindness of Mr. Chester, superintendent of the water company, a gage was erected on the river near the waterworks and daily readings taken from it.

At Carlyle, about 70 miles down the river from Shelbyville, samples were collected from the pump at the waterworks, the intake pipe of which extends about 400 feet upstream. Mr. George Schilling, superintendent of waterworks, collected the samples. A gage was fastened to a tree near the bank of the river and readings of the height of the water were made daily after November 3, 1906.

Quality of water.—Analyses of the composite samples from Shelbyville and Carlyle are given in Tables 35 and 36. The percentage composition of filtered water at Shelbyville and Carlyle is given in Table 10.

TABLE 10.—*Percentage composition of dry residue from filtered Kaskaskia River water.*

	Shelbyville.	Carlyle.
Carbonate (CO_3)	45.4	42.1
Sulphate (SO_4)	12.0	13.7
Chlorine (Cl)	2.0	2.8
Nitrate (NO_3)	2.4	1.9
Calcium (Ca)	18.7	18.9
Magnesium (Mg)	9.2	8.0
Sodium and potassium (Na+K)	4.6	5.6
Iron oxide (Fe_2O_3)	.1	.2
Silica (SiO_2)	5.6	6.8
	100.0	100.0
Salinity, parts per million	284	249

Kaskaskia River water is a typical Illinois water. There is no very great difference in the character between the samples at the two stations, the range in dissolved solids being about the same at each. The average variation, however, is greater at Carlyle, being 11 per cent of the mean value, while at Shelbyville it is only 7.8 per cent. The water is more suitable for boiler use than for laundries. It forms very little or no hard scale in boilers when they are cleaned often enough. Treatment with lime alone in the proper quantities would very much improve the quality of the water for laundry work.

MUDDY RIVER.

Drainage.—Muddy River drains an area of nearly 2,400 square miles in the low district north of the Ozark uplift. The lower 20 miles of the course of the river is in the Mississippi River bottoms. The drainage basin is decidedly level, and there is only a slight fall in the river from its source to the mouth. The flow is very unsteady, the range in height at Murphysboro during the year covered by this report being 31 feet.

Samples.—Daily samples of water were collected from the intake at the waterworks at Murphysboro by Mr. H. C. Stagner, chief engineer. A gage was placed on the river in November, 1906, and readings were taken at the time of the collection of the samples.

Quality of water.—Analyses of the composite samples from the Muddy are given in Table 37, together with averages for the year and gage readings. The percentage composition of the dry residue is given in Table 17 (p. 53).

The water of Muddy River is the most variable in character of all those examined for this report. This may be due, in some measure, to the different characteristics of the tributaries, but it is probably due more to contamination by mine drainage, the variations being very much the same as those noted by M. O. Leighton,[a] of the United States Geological Survey, in his careful study of the influence of mine drainage on Susquehanna River in Pennsylvania. From the low value of the bicarbonate occurring at certain times with very high values for the sulphates, it is probable that at times the water from the Muddy is actually acid. If the water were acid for one or two days out of the ten on which the daily samples were collected to make a given composite, the composite sample might easily be slightly alkaline.

Like the other streams in the southern part of the State, Muddy River carries a large amount of very fine suspended matter. Much of this material, which seems to be really suspended matter and not color, can not be held by any ordinary method of filtration, but by the use of a coagulant the water may be rendered perfectly clear and almost colorless. This finely divided suspended matter accounts, in part, for the fact that the values for silica in Muddy River are very high. In nearly every sample where the silica was high there was left after treatment with hydrofluoric acid a residue, amounting to 1 to 5 parts per million, which was insoluble in hydrochloric acid and not volatilized by hydrofluoric acid. Several of these residues were analyzed by fusing them with acid sodium sulphate and making a complete analysis of the fused mass. The precipitate with ammonia, that is, the iron and aluminum, on ignition weighed in every case

[a] Quality of water in the Susquehanna River drainage basin: Water-Supply Paper U. S. Geol. Survey No. 108, 1904.

almost exactly the same as the original silica residue. The iron in this insoluble residue was usually a very small proportion of the whole. This would indicate that the finely divided matter is an aluminum silicate.

In analyzing similar waters at the Washington laboratory, alumina cream was used for clarifying the samples and removed the suspended matter without affecting the silica dissolved in the water. A number of experiments were made to compare the effect of the treatment using alumina cream with that of the Berkefeld filter, and the filtrates from the two treatments were found to give the same results on analysis. It was found necessary in these experiments to use alumina cream in clarifying the sample on which the determination of bicarbonates was made. If this method of analysis had been adopted on all rivers of southern Illinois, the results would have been more uniform and would have represented more accurately the material dissolved in the water. They would also have shown the kind of water that would have been obtained by the use of a mechanical filtration plant.

Municipal supplies.—In the section of Illinois drained by Muddy River there is no large supply of satisfactory underground water. According to analyses [a] by the Illinois State Water Survey, water from the municipal supply at Carbondale, which is obtained from deep wells, contained at different times from 1,200 to 2,400 parts per million of dissolved matter, about three-fourths of which was common salt. In addition, there are enough salts of magnesium and calcium to make the water about as hard as that of the Muddy. This, of course, makes it undesirable for domestic use. With such water in the wells the only chance for a sufficient municipal supply lies in the use of a river water, even though its quality is much inferior to that of most of the rivers of northern Illinois, where well waters are used almost exclusively.

Water such as that of Muddy River can be purified only by careful treatment with some coagulant and proper filtration. For much of the year water from the Muddy can be clarified only by the use of aluminum sulphate with lime, but the amount of lime required will vary greatly from day to day. In softening the water for use in steam boilers or in laundries, the proper amounts of chemicals to be added can be determined only by tests on each lot of water treated.

MISSISSIPPI RIVER.

Municipal supplies.—Mississippi River forms the western boundary for the whole State of Illinois. The cities of Moline, Rock Island, Quincy, Alton, East St. Louis, and Cairo, located on the river, are important manufacturing centers. The first five of these and two

[a] Bartow, Edward, Municipal water supplies of Illinois: Bull. Univ. Illinois, October 21, 1907.

smaller cities obtain water from the river for municipal supply. In this way about 125,000 persons use the river water. On the opposite bank in Iowa and Missouri are more cities that use the river water and serve many more consumers. The magnitude of the whole river as compared with the stretch flowing past Illinois makes it necessary in this report to discuss merely the quality of the water in the part of the river bounding the State. The river as a whole is discussed in a paper by R. B. Dole.[a]

At the cities where the river furnishes the supply of water for domestic use some method of purification is used. Much of the suspended matter is removed by sedimentation in storage basins, and commonly a coagulant is used with filtration.

Samples.—Daily samples were collected at Quincy and Chester for a year, beginning August 1, 1905, and at Moline for half a year, beginning February 1, 1907. Collections were made by the superintendents of the waterworks, Mr. Magnus Olsen, at Moline, and Mr. F. J. Brinkoetter, at Quincy. In both these places samples were collected from the pump taking water from the river for the filter beds. At the southern Illinois penitentiary, at Chester, Mississippi River water is pumped from the river to a small reservoir and thence distributed through the grounds. Through the kindness of the warden, Mr. James B. Smith, samples were collected each day from the intake pump.

Quality of water.—Analyses of composite samples, made up of ten daily samples for each of these stations, are given in Tables 38, 39, and 40. As would be expected, the suspended matter and dissolved matter both increase in amount as one goes down the river. The percentage composition of dry residue from the filtered water is given in Table 11.

TABLE 11.—*Percentage composition of dry residue of filtered Mississippi River water.*

	February 1 to July 31, 1907.			August 1, 1906, to July 31, 1907.	
	Moline.	Quincy.	Chester.	Quincy.	Chester.
Carbonate (CO_3)	42.3	42.9	32.1	43.2	33.2
Sulphate (SO_4)	13.6	12.9	22.7	12.6	21.8
Chlorine (Cl)	2.1	1.9	3.3	2.2	3.8
Nitrate (NO_3)	1.0	1.2	1.4	1.1	1.0
Calcium (Ca)	18.7	19.1	17.6	18.1	17.1
Magnesium (Mg)	7.3	7.7	6.3	8.0	6.2
Sodium and potassium (Na+K)	5.7	5.2	7.8	5.5	8.2
Silica (SiO_2)	9.0	8.8	8.6	9.0	8.5
Iron oxide (Fe_2O_3)	.3	.3	.2	.3	.2
	100.0	100.0	100.0	100.0	100.0
Salinity, parts per million	177	194	256	199	258

[a] The quality of surface waters in Mississippi River basin: Proc. Illinois Water-Supply Assoc., 1910.

As the samples at Moline were collected during six months only, the average at Quincy and Chester has been calculated for this period, and the percentage composition is given for the six months as well as for the whole year.

The percentage composition does not change much between Moline and Quincy. The only tributaries of any considerable size entering the river between these points are Des Moines and Rock rivers. The water of Des Moines River does not differ very much in quality from that of the Mississippi at Moline, though it contains a somewhat larger amount of dissolved solids and a somewhat smaller proportion of magnesium. Rock River carries about the same amount of dissolved solids as Des Moines River, but the proportion of magnesium is very much higher than in either the Des Moines or the Mississippi at Moline.

Between Quincy and Chester the main tributaries are Illinois and Missouri rivers. Illinois River water is not very different from that of the Mississippi at Quincy, though it probably contains a smaller amount of dissolved material, a larger amount of chlorine, and a somewhat higher percentage of magnesium. But the water of Missouri River is very different from that of Mississippi River at Quincy or that of Illinois River at its mouth. Missouri River carries a very much larger amount of dissolved material which contains a much higher percentage of sulphate and a correspondingly lower percentage of carbonate. It has a somewhat higher proportion of chlorine. The sodium is decidedly higher, while the magnesium is lower and the calcium slightly lower than at Quincy. As the flow of the river at Chester is on the average about one-half Missouri River water and the other half upper Mississippi and Illinois River water, these characteristics of Missouri River water make themselves felt in the character of the Mississippi water at Chester.

Variations at Quincy.—Discharges of Mississippi River at Quincy have been calculated by using Weather Bureau gage readings at Hannibal, Mo., together with a rating table prepared by Herman Stabler from various discharge measurements by the U. S. Engineer Corps and the United States Geological Survey. In Table 12 are given the discharges at Hannibal, the dissolved solids at Quincy, and the discharge of dissolved material in tons per twenty-four hours calculated from these figures. The average variation in discharge was 32 per cent of the mean value; the average variation in dissolved solids was 8.6 per cent of the mean value, and the average variation in amount of dissolved solids per day was 30 per cent of the mean value. The fact that the amount of solids per day does not vary as much as the discharge is due to the fact that in times of high discharge the proportion of dissolved solids is usually lower than in times of low discharge.

TABLE 12.—*Dissolved solids in Mississippi River at Quincy.*

Date.	Discharge (second-feet) [a]	Dissolved solids.	
		Parts per million.	Tons per 24 hours.
1906.			
August 1–August 10	54,000	224	37,600
August 11–August 20	65,000	192	38,600
August 21–August 30	58,000	197	30,800
August 31–September 9	56,000	213	32,200
September 10–September 18	59,000	187	29,800
September 20–September 29	59,000	196	31,200
September 30–October 9	60,000	200	32,400
October 10–October 18	52,000	213	29,900
October 20–October 31	43,000	220	25,500
November 1–November 8	47,000	223	28,300
November 9–November 19	58,000	185	28,900
November 20–November 30	59,000	196	31,200
December 1–December 10	67,000	217	39,200
December 11–December 20	51,000	190	26,200
December 21–December 25	28,000	244	18,400
1907.			
January 2–January 10	58,000	210	32,800
January 11–January 20	62,000	237	39,600
January 21–January 31	100,000	203	54,800
February 2–February 9	40,000	218	23,500
February 10–February 18	48,000	239	30,900
February 19–February 28	59,000	207	33,000
March 1–March 10	65,000	188	33,000
March 12–March 19	73,000	192	37,800
March 21–March 31	78,000	193	40,600
April 1–April 10	108,000	180	52,400
April 11–April 20	158,000	144	61,300
April 21–April 30	141,000	170	64,600
May 1–May 10	97,000	176	46,000
May 11–May 20	80,000	213	45,800
May 21–May 31	86,000	176	40,800
June 1–June 10	82,000	188	41,600
June 11–June 20	117,000	200	63,100
June 21–June 30	97,000	218	57,000
July 1–July 10	88,000	227	53,800
July 11–July 20	143,000	211	81,400
July 21–July 31	160,000	239	103,200
Average	77,000	204	41,600

[a] At Hannibal, Mo.

In studying the analyses at Quincy and Moline, together with analyses made in the Iowa City laboratory of the Survey [a] on samples of water from Minnesota River at Shakopee and Des Moines River at Keosauqua, it is seen that there is an increase in dissolved solids at Quincy and Moline in the latter part of June and July, at a time of high flow. Minnesota River has a drainage area of about 16,000 square miles, between one-fifth and one-sixth the drainage area of Mississippi River at Moline. The rise in the Mississippi at Moline and Quincy in June and July, 1907, was to a considerable extent due to high water from the Minnesota. As the average value for dissolved solids of the Minnesota during this period was over 400 parts per million, this fact would account for the increase in these solids at Moline and Quincy concordantly with the increase in the discharge.

[a] Dole, R. B., Quality of surface water of the United States, pt. 1: Water-Supply Paper U. S. Geol. Survey No. 236, 1909.

Variations at Chester.—Discharges of Mississippi River at Chester have been assumed to be equal to the discharge at St. Louis. It is probable that the discharge at Chester is from 1 to 3 per cent higher than at St. Louis, but no rating table was easily obtainable for the river at Chester, whereas a fairly satisfactory rating table was obtained for St. Louis. From the Weather Bureau gage readings and a rating table which was prepared by Stabler, discharge measurements were calculated for the river at St. Louis for each ten-day period covered by the analyses. In Table 13 these figures are given, together with the dissolved solids in parts per million and the amount of dissolved solids carried by the river at Chester.

TABLE 13.—*Dissolved solids in Mississippi River at Chester.*

Date.	Discharge (second-feet).[a]	Dissolved solids.	
		Parts per million.	Tons per 24 hours.
1906.			
August 1–August 10	140,000	320	121,000
August 11–August 20	159,000	237	101,700
August 21–August 30	155,000	245	102,600
August 31–September 9	132,000	256	92,600
September 10–September 19	117,000	249	78,400
September 20–September 29	130,000	260	91,100
September 30–October 9	156,000	228	95,800
October 10–October 19	112,000	266	80,400
October 22–October 31	89,000	306	73,400
November 1–November 7	96,000	316	81,800
November 15–November 19	112,000	310	93,700
November 20–November 30	119,000	254	81,500
December 1–December 10	130,000	265	93,000
December 11–December 20	115,000	271	84,000
December 22–December 31	71,000	301	57,600
1907.			
January 1–January 10	105,000	271	76,600
January 11–January 19	148,000	260	103,700
January 21–January 30	374,000	222	224,000
February 1–February 9	181,000	214	104,500
February 10–February 18	124,000	277	92,600
February 21–February 28	180,000	304	147,900
March 1–March 10	188,000	266	135,000
March 11–March 20	216,000	257	149,500
March 21–March 30	203,000	238	130,000
April 1–April 10	225,000	255	154,500
April 15–April 20	257,000	297	205,600
April 22–April 29	279,000	256	192,400
May 21–May 31	214,000	293	168,800
June 3–June 10	281,000	284	215,200
June 11–June 20	329,000	265	235,200
June 21–June 29	334,000	296	266,700
July 1–July 10	320,000	294	253,600
July 11–July 19	317,000	304	260,000
July 21–July 31	484,000	250	326,200
Average	194,000	270	140,300

[a] At St. Louis.

The average variation in discharge of the Mississippi at Chester is 40 per cent of the mean value of the discharge; the average variation in dissolved solids is 8.5 per cent of the mean value, and the average variation in the solids carried per day is 41 per cent. It is unusual that the solids carried per day should vary more than the discharge,

for this would indicate that in times of high water there was more material dissolved in the river than in times of low water. In order to see if this could be accounted for, calculations were made as to the amount of dissolved material carried by each of the three component streams making up the Mississippi at Chester. For this purpose monthly average gage heights and discharge measurements were computed by Mr. Stabler.

The volume of upper Mississippi water reaching Chester was assumed to be measured by discharges at Hannibal, Mo., which correspond to the analyses at Quincy, Ill. No discharge measurements are available for the Illinois below Peoria, and as the drainage area of Illinois River at its mouth is very much greater than at Peoria, the proportional effect of Illinois River would not be at all accurately represented by taking discharges at Peoria. Estimates by Cooley,[a] however, indicate that the discharge of the Illinois into the Mississippi is probably about 1.75 times the discharge at Peoria, and therefore in the calculations 1.75 times the discharge at Peoria was used as representing the amount of Illinois water reaching Chester, while the analyses at Kampsville were used as representing its quality. The amount of Missouri River water reaching Chester was represented by the discharge measurements at St. Charles, Mo. In Table 14 are given these discharges for each month, together with the sum of the three discharges and the discharges as calculated for Mississippi River at St. Louis. It will be seen that in general the sum of the three discharges is somewhat greater than the estimated discharge of the Mississippi at St. Louis. It is not likely, however, that the proportional error is very serious.

TABLE 14.—*Discharges of Mississippi, Illinois, and Missouri rivers at points stated.*

[In thousands of second-feet.]

Date.	Mississippi River at Hannibal.	Illinois River at Kampsville.[b]	Missouri River at St. Charles.	Sum.	Mississippi River at St. Louis.
1906.					
August	70	12	84	166	151
September	58	13	63	134	126
October	50	14	52	116	113
November	56	14	51	121	111
December	47	24	39	110	102
1907.					
January	71	47	87	205	198
February	49	43	63	155	157
March	72	35	99	206	202
April	133	36	96	265	251
May	88	31	118	237	242
June	102	34	191	327	307
July	128	35	225	388	370

[a] Cooley, L. E., The Illinois River basin in its relation to sanitary engineering, Illinois State Board of Health, 1889.

[b] 1.75 times the discharge at Peoria.

In Table 15 is given the percentage of the discharge at Chester which is furnished by each river; the average value for the dissolved solids in these rivers; one one-hundredth of the product of these two figures, which shows the contribution of each river to the dissolved solids in Mississippi River at Chester; the sums of these three components; and the value for dissolved solids at Chester as obtained by averaging the values for the three composite samples of each month. The figure for May is of almost no value, as samples were not received during the first twenty days of that month and only one analysis was made during the month.

It is evident that this method of calculating the dissolved solids in Mississippi River water at Chester does not give the correct result, the value being higher than those found. This would indicate a possible lack of complete mixing of Missouri River with Mississippi River at the point where the samples were collected. Another explanation would be the undue influence of Kaskaskia River, which enters a short distance above Chester. The drainage area of Kaskaskia River is not over 3,000 miles, so that its contribution to the flow of the Mississippi is almost negligible. If, however, its water is not thoroughly mixed with the other water coming down the Mississippi, the samples collected at Chester might have too large a proportion of Kaskaskia River water. In order to determine this point, curves were plotted showing (1) dissolved solids calculated from the analyses and discharges of upper Mississippi, Illinois, and Missouri rivers; (2) dissolved solids as found by analysis at Chester; (3) dissolved solids as found in the Kaskaskia at Carlyle. It appears from inspection of these curves that the dissolved solids found at Chester follow very closely the dissolved solids as calculated. The variations from the curve of calculated values are the same as the variations in the values for the dissolved solids in the Kaskaskia. The greatest difference between the calculated and determined values is only about 8 per cent of the former. Inspection of Table 15 shows that in the latter part of the year Missouri River furnished a very large proportion of the flow at Chester. The dissolved solids from Missouri River are very much higher than the average value for dissolved solids in Mississippi River. This then would cause an increase in dissolved solids in Mississippi River at the same time that the discharge increased. Thus when the discharge is doubled the amount of dissolved matter carried by the stream is more than doubled, as the water contains in each cubic foot much more than the average amount of dissolved matter.

TABLE 15.—*Composition of and average solids in Mississippi River at Chester.*

Date.	Percentage of discharge at Chester.			Dissolved solids (parts per million).		
	Mississippi River at Hannibal. (a)	Illinois River at Kampsville. (b)	Missouri River at St. Charles. (c)	Mississippi River at Quincy. (d)	Illinois River at Kampsville. (e)	Missouri River at Ruegg, Mo. (f)
1906.						
August	42.2	7.2	50.6	204	263	.....
September	43.3	9.7	47.0	199	236	.....
October	43.1	12.1	44.8	211	297	375
November	46.3	11.6	42.1	201	263	429
December	42.7	21.8	35.5	217	301	403
1907.						
January	34.6	22.9	42.5	217	247	325
February	31.6	27.8	40.6	221	206	337
March	35.0	17.9	48.0	191	232	317
April	50.2	13.6	36.2	165	286	370
May	37.1	13.1	49.8	188	289	311
June	31.2	10.4	58.4	202	288	338
July	33.0	9.0	58.0	236	261	307

Date.	Dissolved solids (parts per million).					
	Mississippi River at Chester.					Kaskaskia River at Carlyle.
	Calculated.				By analysis.	
	Upper Mississippi River water. $\left(\frac{a \times d}{100}\right)$ (g)	Illinois River water. $\left(\frac{b \times e}{100}\right)$ (h)	Missouri River water. $\left(\frac{c \times f}{100}\right)$ (i)	Sum. (g+h+i)		
1906.						
August	86.0	18.9	.....	.....	267	237
September	86.1	22.9	.....	.....	255	261
October	90.8	35.9	168	295	267	223
November	93.0	30.5	181	304	293	245
December	92.7	65.6	144	302	279	256
1907.						
January	75.0	56.5	138	270	251	191
February	69.8	57.2	137	264	265	259
March	66.8	39.4	152	258	254	235
April	82.8	38.9	134	256	269	280
May	69.7	37.8	155	262	(293)	264
June	63.0	30.0	198	290	282	221
July	77.8	23.5	178	279	283	264

It is evident from inspection of the tables that Mississippi River above the Missouri is not remarkably turbid as compared with other streams of the Middle West. Its turbidity averages about the same as that of other rivers in Illinois. At Chester the turbidity resembles that of the Missouri. Usually the suspended matter causing this turbidity is composed of fairly large particles which quickly settle so that the water can be clarified easily by mere sedimentation. At times, however, the turbidity is caused by material so fine that it is exceedingly difficult to filter. This excess can be recognized in the analyses by the high values for silica. It is probable that in most

samples where the value for silica is over 25 parts per million, the excess over this figure is due to suspended matter which was not removed by filtration. On account of the large proportion of sulphate in Missouri River water, Mississippi River water below the mouth of the Missouri is much less satisfactory for industrial purposes, even after purification. Above the Missouri, Mississippi River water is of much the same quality as most ground and stream waters throughout Illinois.

WABASH RIVER SYSTEM.

The drainage basin of Wabash River has an area of over 33,000 square miles. It extends westward from western Ohio across the central portion of Indiana and southward to Ohio River. It embraces on its west side a considerable portion of southeastern Illinois. Drainage from Illinois into Wabash River is carried by Vermilion, Embarrass, and Little Wabash rivers. Bonpas River drains a small area between Embarrass and Little Wabash rivers.

WABASH RIVER.

Municipal supplies.—The Wabash forms the boundary of the State on the east and south for a distance of nearly 200 miles by river. Its water is usually rather turbid and probably contains more dissolved mineral matter than well waters which may be obtained along its banks. For these reasons it is not likely to be used as a source of supply, except for communities too large to find a sufficient quantity in wells. There are not many large cities in Illinois directly on the river. Grayville and Mount Carmel, however, obtain their water supplies directly from it.

VERMILION RIVER.[a]

Drainage.—Vermilion River drains an area of about 1,500 square miles in northern Illinois. The river rises in the Bloomington morainic system at the reentrant angle in Ford and Livingston counties, only a few miles from the source of the other river of the same name, which flows northward to the Illinois. From its source Vermilion River flows east and southeast, entering the Wabash in Indiana. In the last 10 miles of its course it receives very little drainage, except from the immediate vicinity of the stream. Its flow is not very rapid and the discharge is somewhat irregular.

Municipal supplies.—The municipal supply of Danville, Ill., is obtained from North Fork of Vermilion River and is purified by filtration after the use of a coagulant.

Samples.—The samples of raw river water were collected by Mr. William Van Steenberg, engineer of the Danville Water Company.

[a] Not to be confused with the Vermilion River that empties into Illinois River.

Quality of water.—Analyses of the composite samples from Danville are given in Table 41, together with the average for the year.

The water of Vermilion River at Danville is very much like that obtained from other rivers draining the part of Illinois covered by glacial drift. The variations in dissolved solids from time to time are not very great. The average variation for the year was 8.4 per cent of the mean value for the dissolved solids. The percentage composition of the water does not vary much with variations in the amount of dissolved solids. The suspended matter is usually of such character that it can be easily removed by filtration. Analyses of ground water from drift along the course of Vermilion River show that for most industrial purposes there is not much choice between the water from the river and that from wells.

EMBARRASS RIVER.

Drainage.—Embarrass River drains an area of about 2,000 square miles in eastern Illinois. Its source is in the Champaign morainic system, immediately south of Champaign, and it flows a little east of south until it enters Wabash River about 6 miles below Vincennes. The flow is very variable. It is said that at times the river goes almost dry at Lawrenceville, 8 miles above its mouth.

Municipal supplies.—The cities of Charleston, Greenup, and Newton obtain their water supply from the Embarrass. At none of these places is the water purified.

Samples.—Daily samples were collected for the year at Charleston and at Lawrenceville. At Charleston the samples were obtained from the pump taking water directly from the river for municipal supply. The intake at the pumping station is about 240 feet south of the pump, near the middle of the river. Collections were made by Mr. James Winkleblack and Mr. Louis Strodbeck, engineers at the waterworks.

At Lawrenceville samples were collected for part of the year by Mr. C. H. Arnold, superintendent of the Lawrenceville Water Company. The supply for the city is obtained from deep wells, and the samples furnished by Mr. Arnold were obtained by dipping the water from the river near the waterworks. For a time the collection of samples at Lawrenceville was omitted, owing to a change in the superintendent of the waterworks, but after October 12, 1906, samples were collected by Mr. Perry Barnhouse at the pumping station of the Big Four Railway from the pump which takes water direct from the river.

Quality of water.—Analyses made on the composite samples from Charleston and Lawrenceville are given in Tables 42 and 43. The percentage composition of the dry residue from the filtered water at these two stations is given in Table 16.

TABLE 16.—*Percentage composition of dry residue from filtered Embarrass River water.*

	Charleston.	Lawrenceville.
Carbonate (CO_3)	45.0	34.5
Sulphate (SO_4)	11.4	12.6
Chlorine (Cl)	1.8	12.6
Nitrate (NO_3)	2.8	1.3
Calcium (Ca)	18.8	15.8
Magnesium (Mg)	8.9	6.8
Sodium and potassium (Na+K)	4.8	10.0
Silica (SiO_2)	6.3	6.1
Iron oxide (Fe_2O_3)	.2	.3
	100.0	100.0
Salinity, parts per million	271	278

The water of Embarrass River at Charleston is very much like all the river waters in the section of Illinois covered by the glacial drift. On account of the fact that the drainage basin above Charleston is somewhat thinly populated, the proportion of sodium and chlorine is lower than in most of the streams of the State. It is probable that the character of the water remains fairly constant through its course down to a point a short distance above Lawrenceville.

The water from the river at Lawrenceville is entirely different from that at Charleston, the change consisting almost wholly of a large increase in sodium and chlorine. Table 43 shows that its percentage composition also varies very much throughout the year. This may be due in large measure to the effect of the water draining from oil wells above Lawrenceville. The beginning of the great activity in the oil industry in southern Illinois occurred during the time covered by these analyses. If the river continues to receive waste waters from the oil wells it will be of very little value as a source of supply either for municipal use or for manufacturing.

LITTLE WABASH RIVER.

Drainage.—Little Wabash River drains 3,000 square miles in southeastern Illinois, entering the Wabash 8 miles in a direct line from the latter's junction with the Ohio. From its source in the Shelbyville morainic system, in southwestern Coles County, it flows slightly west of south for 50 miles and then east of south to its mouth, a distance in a direct line of about 75 miles. Its largest tributary is Skillet Fork, which has a drainage area of about 1,000 square miles and a length in a straight line of about 65 miles; it enters the Little Wabash from the west just above Carmi.

Municipal supplies.—The cities of Effingham and Carmi are supplied with water from the Little Wabash. No analyses were made of the water at Effingham, but an analysis by the Illinois State Water

Survey[a] indicates that it resembles the river waters of northern Illinois. The water at Carmi is pumped from the river to a standpipe, from which it is distributed through the mains.

Samples.—Samples were collected from the river at Carmi by Mr. Samuel Morgan, engineer of the waterworks.

Quality of water.—Analyses of the composite samples from Carmi are given in Table 44. The percentage composition of the dry residue is given in Table 17.

The quality of water at Carmi is exceedingly variable, probably owing in some measure to the influence of Skillet Fork, the drainage basin of which is typical of southern Illinois. The average variation in dissolved solids at Carmi is 17 per cent of the mean value, and the range from maximum to minimum is 73 per cent of the mean value.

During the greater part of the time water from Little Wabash contains a large amount of finely divided material which can not be removed by any simple filtration. On account of the small amounts of calcium and magnesium in the water it is very satisfactory for use in steam boilers or for any other purpose where the turbidity and iron do not cause inconvenience.

CACHE RIVER.

Drainage.—Although Ohio River once discharged wholly or in part through the Cache Valley, the region now drained by Cache River has an area of only about 600 square miles, comprising the great part of the State south of the Ozark ridge. There are extensive swamps in the drainage basin of Cache River, but it is nevertheless subject to floods of considerable magnitude.

Samples.—Daily samples were collected and daily gage heights read by Mr. J. F. Anderson at the Illinois Central pumping station where the railroad crosses the river below Mounds.

Quality of water.—Analyses of the composite samples from Mounds are given in Table 45. In Table 17 is given the percentage composition of an average analysis for each of the three rivers draining the southern part of the State. Although the Muddy differs from the other two more than they do from each other, still the similarity of the three waters is evident from a study of the percentage composition. They all contain a much larger percentage of sodium salts than the rivers of northern Illinois. The proportion of magnesium to calcium is very much less than in the northern rivers. The Muddy contains more sulphate than carbonate on account of the mine drainage referred to on page 40. The proportion of silica in these streams is much larger than that in the northern rivers. Part of this silica is not actually in solution in the water but is in the finely divided suspended matter which was not removed. In the sum of the

[a] Bartow, Edward, Municipal water supplies of Illinois: Bull. Univ. Illinois, October 21, 1907.

radicles, which is given in Table 17 as salinity, no account is taken of the material insoluble in hydrochloric acid and not volatilized by hydrofluoric acid, although this amounted in many samples to as much as five parts per million. On this account the salinity is noticeably lower than the values obtained for the dissolved solids.

With the exception of the waters of some reservoirs or ponds, certain shallow wells, and Lake Michigan, these river waters are the softest in the State and are thus excellent for use in steam boilers. The large amount of iron, which can not be removed without a coagulant, makes the waters unsatisfactory for laundry use.

TABLE 17.—*Percentage composition of dry residue from filtered river water in southern Illinois.*

	Muddy River at Murphysboro.	Little Wabash River at Carmi.	Cache River at Mounds.
Carbonate (CO_3)	17.1	27.5	31.1
Sulphate (SO_4)	35.0	20.3	14.0
Chlorine (Cl)	6.2	4.7	5.0
Nitrate (NO_3)	1.0	1.3	1.5
Calcium (Ca)	12.2	12.6	14.0
Magnesium (Mg)	5.6	5.8	4.4
Sodium and potassium (Na+K)	9.9	9.5	11.1
Silica (SiO_2)	11.5	16.5	16.2
Iron oxide (Fe_2O_3)	1.5	1.8	2.7
	100.0	100.0	100.0
Salinity, parts per million	206	158	136

OHIO RIVER.

Ohio River is used as a source of supply by the cities of Golconda and Metropolis, and at one time furnished part of the municipal supply of Cairo. No analyses were made in Illinois of water from Ohio River, as it has been extensively studied at a number of places, especially Cincinnati and Louisville, where it is used as a source of city supply. It is the usual turbid, hard water of a stream entering the Mississippi from the east. Where well water can be obtained along its shores, it is usually much better than the river water, so that the only use for the river water is in cities too large to be supplied by wells.

MUNICIPAL SUPPLIES.

It is usually believed that any community with a population of over 1,000 should have a common water supply. Many cities in Illinois with less than 1,000 inhabitants have municipal supplies, while only a few with more are without one, and most of these are considering the question of installing a waterworks system.

WELLS.

For individual supplies wells have long been the most satisfactory source. In Illinois these may be shallow wells 15 to 30 feet deep,

wells in drift 70 to 150 feet deep, or wells in rock 500 to 2,000 feet deep. Probably the number of supplies from shallow wells is greater than that of all other kinds put together. The number of persons served by such wells is, however, not over half the population of the State, for very few large supplies are obtained from this source.

Over a great part of the State wells 70 to 150 feet deep furnish an abundant supply of water. In many places this water is of such a nature that on exposure to the air it becomes turbid and furnishes opportunity for the growth of microscopic organisms which give unpleasant tastes or odors to the water. The city supplies at Champaign and Bloomington are of this type. Water from shallow wells is subject to pollution, and in any fairly densely populated community almost certain to be unsafe for drinking, but wells deep in the drift give a water that is perfectly safe.

A number of individuals and several cities obtain a supply of water from deep wells in rock. At most of the cities, as Sterling, Rockford, and Elgin, this water, in addition to being perfectly safe to drink, contains less dissolved mineral matter than surface waters or shallow well waters in the same neighborhood. These deep-well waters may be drawn upon at a normal rate for a very long time without showing any loss of head, but nearly everywhere the quantity which can be obtained, even by increasing the number of wells, is decidedly limited. This has driven many cities to adopt surface water as a source of supply.

SURFACE SUPPLIES.

UNTREATED WATERS.

Almost any surface water in Illinois is sure to be polluted and dangerous to use for drinking. The largest user of surface water in the State is the city of Chicago, which is supplied by water from Lake Michigan. This water has in times past been so seriously polluted as to have a decided effect upon the death rate of the city, but within the last few years improvements have been made which render it reasonably safe. The intakes have been extended so that water is pumped from a distance of 2 to 4 miles from the shore, making it probable that the water will be free from any accidental small pollution which may reach the lake. The opening of the Chicago drainage canal removed practically all the Chicago sewage from Lake Michigan. A few cities obtain supplies from reservoirs fed by springs or small streams with an uninhabited drainage basin, and these supplies, with careful supervision, may be kept free from contamination.

PURIFICATION.

By far the greater number of Illinois cities of large size obtain their water supplies from surface waters which are badly polluted. Fortunately for the health of the community, most of these sources of

supply furnish a water of high turbidity, which must be removed to make the water attractive in appearance. In many places this turbidity is caused by particles of extremely small size, often of a size comparable with that of bacteria, and any process which will effectively remove them will at the same time remove the bacteria which may be dangerous. In several cities where no purification of the water is attempted, the municipal supply is not used for domestic purposes.

Sedimentation.—The simplest method of purification of a turbid water is mere sedimentation. If a number of the surface waters of Illinois are subjected to sedimentation for a few days a large proportion of the suspended matter will be removed, but for most waters of the State mere sedimentation is not likely to prove satisfactory. The suspended matter consists of particles so small that they settle very slowly, and to allow sufficient time for satisfactory sedimentation would require the building of very large storage reservoirs. The amount of land necessary for these reservoirs, together with the cost of construction, makes this method out of the question for the clarification of the water.

Sand filtration.—At a few places in Illinois purification of the water is accomplished by means of slow sand filtration. If a water is comparatively free from turbidity, slow sand filtration is a very effective method of purifying it. Ordinarily turbidity and bacteria are very effectively removed and the effluent is clear and safe for drinking. The changes in the mineral content of the water caused by filtering through a layer of sand and gravel 3 to 6 inches deep are, however, not of any consequence.

Mechanical filtration.—Illinois waters very rarely lend themselves to treatment by slow sand filtration, on account of the fineness of their suspended matter, and to meet the needs of water of this class the process known as mechanical filtration has been devised. In this process the water is treated with a certain amount of some chemical or chemicals which will form a large, flaky precipitate or, as it is called, coagulant. The water with this precipitate is then flowed upon a filter of coarse sand, through which it filters very rapidly, giving an effluent perfectly clear and fairly free from bacteria. In this process the filters soon become clogged with the precipitate which holds the bacteria and suspended matter of the water. Therefore after running a short time the supply of water is shut off and clear filtered water is forced back through the sand to wash away the film of precipitate from the top. This process wastes some of the pure filtered water. One disadvantage of this form of treatment is that it requires much more expert attention than a slow sand filter. Another disadvantage is that, as sometimes operated, the effluent from a mechanical filtration plant is much less satisfactory than the untreated water for many industrial uses.

Some of the early mechanical filtration plants accomplished the removal of silt and bacteria by the addition of no chemical except aluminum sulphate, which, reacting with the calcium and magnesium bicarbonates of the water, would give a precipitate of aluminum hydroxide. This precipitate is the best coagulant known. It carries down with itself all the finely divided suspended matter, much of the color of the water, and a very large proportion of the bacteria.

With a water deficient in bicarbonates, it is sometimes difficult to obtain a satisfactory precipitate by the addition of aluminum sulphate alone. In the early days of mechanical filtration about the only directions furnished by those who erected the plants were that when the water was clear a small amount of alum should be added and that when the water became turbid a larger amount should be used. At the time when analyses were being made for this report difficulty was experienced at the Kankakee waterworks in obtaining satisfactory clarification for the water, which was at a very high stage.[a] Aluminum sulphate was being added to the water at the rate of about 14 grains to the gallon. From analyses of the composite samples from Kankakee River at this time, however, it was evident that all the bicarbonates in one gallon of water would combine with only about 2 grains of alum, leaving for the consumers the other 12 grains which was being added to the water. Thus the aluminum sulphate was being wasted, the water was rendered less valuable to the consumers, and it was not clarified in a satisfactory manner. At present the Kankakee River water is being treated before filtration with lime and sulphate of iron in such proportions as to improve the character of the water for industrial purposes, and at the same time to make it clear and safe for drinking.

Softening.—For a number of years the Mississippi water at Quincy has been treated with lime and sulphate of iron in such proportions as materially to decrease its hardness. If the water is thus softened the amount of scale-forming materials will be so much decreased that with care in operation there will be much less scale formed than with the untreated water. In some studies which have been made by the Illinois State Water Survey[b] it has been pointed out that the cost of partial softening is in many cases a very small proportion of the cost of softening to the greatest possible extent; and it is probable that with proper management most of the surface waters of Illinois that are used for municipal supply could be softened to such an extent as to increase their value materially without adding very much to their cost. No municipality in Illinois attempts to remove the

[a] Mr. Cobb, superintendent of the waterworks, has described this experience in a paper read before the Illinois Society of Engineers and Surveyors. See Eng. News, vol. 59, p. 119.

[b] Bartow, E., and Lindgren, J. M., Some reactions during water treatment: Jour. Am. Chem. Soc., vol. 29, p. 1293.

permanent hardness from water, the softening consisting merely in adding to the water more lime than is necessary to combine with the sulphate of iron or aluminum which is used to furnish the coagulant for clarification.

INDUSTRIAL USES OF WATER.

GENERAL STATEMENT.

Of the water used in Illinois, where the amount and character of the dissolved mineral matter are of great importance, by far the largest quantity is used in the production of steam power. Many other extensive uses, however, require water of the same quality as is needed for the generation of steam; for instance, in slaughtering and preparing meat products much hot water of that grade is required. Laundry work can not be well done with a water containing a large amount of calcium or magnesium salts, or with water that is not clear and free from iron. The quality of distilled and malt liquors depends very largely on the kind of water used in the treatment of the grain. Calcium sulphate is said to have a beneficial effect, but large quantities of sodium or calcium chloride are supposed to be injurious. Of course a clear water free from organic matter is to be desired. The distilleries in Illinois generally use well water. The manufacturers of soap, candles, glucose, leather, and several minor products all require certain degrees of purity in the water used. In the manufactured iron, steel, and foundry products, on the other hand, the chief requirement in the way of water is for power. In general, the best water for industrial use is clear, soft water.

LAUNDRY WATER.

Very few river waters of Illinois are suitable for laundry work without some form of purification. Those in the northern part of the State are hard and most of those in the southern part, where some river and reservoir waters are soft enough to be used, are turbid and contain much iron. For individual family washing the problem is easily solved in all parts of the State, as the rainfall is great enough to furnish a supply of rain water at all times of the year if a cistern of sufficient capacity is constructed and the rain collected on the roof is stored in the cistern.

This method, however, is not usually possible for laundries which, in Illinois, must nearly always soften their water supply in some manner, whatever its source. To use enough soap to soften the water and then make a suds is very expensive and usually unsatisfactory. The calcium and magnesium in the water form insoluble soaps which are not easy to remove from the clothes and which make spots when the articles are ironed. Many laundries soften the water

by the liberal use of lye and other chemicals which are applied in no very definite amounts. The most satisfactory and economical method for softening ordinary Illinois waters for laundry use is by a plant such as is used for treating boiler-feed water. Where such a plant has been properly installed and has been managed with ordinary care, the saving in soap or softening chemicals has paid for the plant in a few years, leaving the improvement in the laundering as clear gain.

STEAM-BOILER WATER.

The census of manufactures of Illinois for 1905 gives the amount of steam power used in the State for manufacturing as 651,578 horsepower. This does not include the power generated by locomotives nor a large amount of steam generated for heating.

It is not easy to figure the amount of water used in the different forms of steam production. The railway locomotive uses up the most. The less efficient types of stationary engines waste much steam and condense little to be fed to the boiler again. Steam-heating plants, on the other hand, condense their steam and return it to the boiler, very little fresh water being added. In manufacturing the practice varies, ranging from one extreme, where, as in a locomotive, no steam is condensed, to the other extreme, where, as in a heating plant, practically all the steam is condensed and used over again.

Troubles in a steam boiler where hard water is used are very largely dependent on the amount of fresh water put into the boiler. Many feed waters contain small amounts of carbonates or bicarbonates and large amounts of chlorine with much magnesium and cause serious corrosion of the shells and tubes of boilers. Such waters are usually best treated by the method outlined below for softening hard waters. A very few surface waters are corrosive. These are found mainly near the coal mines, where the water is made acid by the mine drainage. Unless the acidity is too great it may be corrected by the use of soda ash, but the best remedy is to avoid water that receives mine drainage.

Nearly all the waters used in Illinois for the production of steam contain large amounts of salts of calcium and magnesium, which cause much trouble in boilers, forming, unless very carefully watched, a considerable amount of scale. If a water contains enough carbonate and bicarbonate to combine with all the calcium and magnesium present, the calcium and magnesium are separated in a flocculent form when the water is fed into a boiler and heated. This material, together with the material suspended in the water, falls to the bottom of the boiler as a soft sludge and may be blown out from time to time. None of the waters that have been analyzed in the preparation of this report, however, contain enough carbonate and bicarbonate to combine with all the calcium and magnesium. As a result, when a boiler using

any of these waters is run for some time, calcium and sulphates accumulate to such an extent that calcium sulphate is precipitated on the shell or the tubes of the boiler. This precipitate serves as a cement and makes a hard coherent mass out of the soft sludge formed by the precipitation of the carbonates, bicarbonates, and suspended matter. This suspended matter, which is often as much as the dissolved material in the water, causes the river waters to form much more scale than would be formed by a clear water containing the same dissolved mineral matter.

SOFTENING.

At many small power plants water in steam boilers is treated with so-called boiler compounds. These compounds are many and greatly varied in character. Their most valuable constituent is soda ash; some compounds contain sugar, tannin, and various other organic substances. Very few of these compounds are any better than plain soda ash and many are worse. Their only advantage is in preventing the formation of hard scale, for, with or without their use, the salts of calcium and magnesium will accumulate in the form of sludge and must be blown out.

In a good many plants, especially in some of moderate size, the water, before reaching the boiler, is purified to a certain extent simply by heating. This causes a separation in the heater of a considerable proportion of the substances which would otherwise be separated in the boiler. This method is not a great improvement over using the water without any purification, the main difference being that the sludge has to be removed from the feed-water heater rather than from the boiler. Sometimes the water in its passage through the heater is treated with sodium carbonate or soda ash; when properly conducted this process insures the removal of practically all the calcium and magnesium, leaving nothing to go into the boiler that can form hard scale.

The best steam-boiler practice is to so soften the water that no calcium and magnesium salts can be precipitated within the boiler. To accomplish this purpose the cold water is usually treated with lime and soda ash, which are dissolved in water either separately or together and mixed in definite proportion with the water to be treated. In ordinary water-softening practice it is customary to add a quantity of lime equivalent to the calcium and magnesium present in the water as bicarbonates, and soda ash equivalent to all the calcium and magnesium not present in the form of bicarbonates. A further quantity of lime is added equivalent to all the magnesium present, whether as bicarbonate or as some other salt. Still more lime is added to unite with the excess of carbon dioxide in the water above the amount necessary to form bicarbonates. Other factors, as

the presence of sodium bicarbonate, iron, aluminum, and other substances, affect the amount of chemicals to be added, but the treatment outlined above has proved satisfactory with many Illinois surface waters. If the dosing is properly done, practically all the lime and magnesium are precipitated, settling to the bottom of the tank in which the reaction is carried out. The clear water is then perfectly satisfactory for use in a boiler. It still contains enough salts of calcium and magnesium to prevent corrosion, but not enough to form any scale if the boiler is blown off reasonably often. River waters in Illinois carry so much suspended matter that it is well worth while to go to some expense to keep it out of a boiler.

In order that the different waters which have been studied for this report may be compared as to their value for the production of steam, the cost of softening has been calculated from the average analysis of the water from each station. In Table 18 are given the results of this calculation, showing the amount of lime and the amount of soda ash needed to soften 1,000 gallons of the water. The cost is figured on the basis of 0.3 cent a pound for pure lime (CaO) and 1.2 cents a pound for pure sodium carbonate (Na_2CO_3). Commercial lime and soda ash can easily be bought at prices enough below these to offset the difference in amount of pure CaO and Na_2CO_3. The figures form an approximate measure of the value of the water for steaming purposes. There is a great difference between the cost of 0.27 cent per 1,000 gallons for Lake Michigan or 0.16 cent for Cache River and the cost of over 1 cent for Vermilion River at Streator or Fox River at Ottawa. The range from 0.6 cent to 1.1 cents per 1,000 gallons will, however, include the river waters which are most used. The rise from about 0.4 cent at Moline and Quincy to 0.65 cent at Chester shows the great influence of Missouri River on the quality of the Mississippi River water.

The actual cost of softening 1,000 gallons of water from any of these rivers would of course be much more than is given in the table, for it must include depreciation of the plant, interest on the investment, and expense of operation. These items depend, however, more on the size of the installation than on the quality of the water. In a few places the great variability in quality causes a slight increase in the cost of operation by requiring special care to make the doses of chemicals correspond to the variations in the water, but it is more usual to allow this variation in quality to appear in the over or under treatment of the water, the dose remaining the same.

TABLE 18.—*Cost of softening Illinois surface waters.*

Source.	Station.	Chemicals required per thousand gallons.		Cost per thousand gallons.
		Lime (CaO).	Soda ash (Na_2CO_3).	
		Pounds.	*Pounds.*	*Cents.*
Lake Michigan	Chicago	0.78	0.03	0.27
Reservoir	Cartter	.20	.08	.16
Do	Marion	.35	.26	.41
Do	Cypress	.39	.16	.31
Do	Joppa	.24	.06	.14
Rock River	Rockford	1.45	.07	.52
Do	Sterling	1.53	.16	.64
Kankakee River	Kankakee	1.23	.48	.94
Fox River	Elgin	1.60	.27	.80
Do	Ottawa	1.67	.49	1.09
Vermilion River (of Illinois River)	Streator	1.48	.52	1.07
Sangamon River	Decatur	1.52	.21	.71
Do	Springfield	1.41	.23	.69
Do	Chandlerville	1.46	.20	.68
Illinois River	La Salle	1.20	.42	.87
Do	Peoria	1.16	.40	.83
Do	Kampsville	1.16	.31	.72
Kaskaskia River	Shelbyville	1.51	.21	.70
Do	Carlyle	1.20	.22	.62
Muddy River	Murphysboro	.51	.47	.71
Mississippi River	Moline	.83	.10	.37
Do	Quincy	.98	.10	.41
Do	Chester	.98	.29	.64
Vermilion River (of Wabash River)	Danville	1.41	.34	.83
Embarrass River	Charleston	1.41	.19	.65
Do	Lawrenceville	1.11	.25	.63
Little Wabash River	Carmi	.51	.14	.32
Cache River	Mounds	.44	.02	.16

CONCLUSIONS.

1. Compared with surface waters of the United States as a whole, the surface waters of Illinois are fairly uniform in quality throughout the State.

2. The best large supply of water in the State is Lake Michigan.

3. Water in the reservoirs and rivers of the southern part of the State is softer than that of northern rivers. The turbidity is less in the northern rivers and is much more easily removed than that of the southern streams.

4. None of the river waters are clear enough to furnish a satisfactory city supply without treatment. Treatment which will clarify the water and give it a pleasing appearance can be made to yield from most rivers a water safe for drinking.

5. The value for industrial use of nearly all the surface waters may be greatly increased by softening.

6. The daily and seasonal variations in quality render necessary careful daily supervision to insure the best results in any form of purification.

7. The quality of Illinois River water is made more uniform by the operation of the Chicago drainage canal.

8. The impounding of flood waters for the purpose of regulating the discharge of the rivers would greatly improve the quality of the water.

The turbidity would be decreased, and the variations in amount of dissolved material would be much less. The extreme values occur in the times of very high and very low water, which would be eliminated by the impounding.

ANALYTICAL TABLES.

TABLE 19.—*Mineral analyses of water from reservoir near Cartter, Ill.*

[Parts per million unless otherwise stated.]

Date (1906–7).		Turbidity.	Suspended matter.	Coefficient of fineness.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.
From—	To—														
Aug. 1	Aug. 10	120	44	0.4	12	0.40	13	6.1	.....	0.0	45	20	3.2	8.2	103
Aug. 11	Aug. 20	50	19	.4	7.4	.50	4.6	4.6	7.1	.0	25	11	1.8	1.2	62
Aug. 21	Aug. 30	60	25	.4	5.8	.55	11	5.7	14	.0	46	16	3.0	2.5	82
Aug. 31	Sept. 9	30	18	.6	7.6	.05	8.0	3.8	5.5	.0	30	10	2.0	2.0	64
Sept. 10	Sept. 19	30	15	.5	9.2	.12	8.1	3.8	5.0	.0	29	12	1.6	2.0	67
Sept. 20	Sept. 29	60	23	.4	5.4	.10	11	4.0	5.7	.0	32	11	2.0	3.0	68
Sept. 30	Oct. 9	.....	.....	.....	.....	.....	.....	.....	.....	.0	.....	.....	.....	.....	.....
Oct. 10	Oct. 13	.....	.....	.....	.....	.....	.....	.....	.....	.0	.....	.....	.....	.....	.....
Oct. 25	Oct. 29	.....	.....	.....	.....	.....	.....	.....	.....	.0	.....	.....	.....	.....	.....
Oct. 30	Nov. 8	30	16	.5	11	.25	11	7.6	8.1	.0	47	17	2.0	3.0	81
Nov. 9	Nov. 19	50	19	.4	7.2	.50	9.1	4.5	8.2	.0	39	18	1.5	4.5	76
Nov. 20	Nov. 30	.....	.....	.....	.....	.....	.....	.....	.....	.0	.....	.....	.....	.....	.....
Dec. 2	Dec. 10	30	17	.6	9.6	1.6	6.4	2.4	11	.0	31	17	2.0	8.7	66
Dec. 11	Dec. 20	100	53	.5	13	2.0	11	5.3	8.6	.0	.....	17	3.0	4.0	93
Dec. 21	Dec. 31	50	26	.5	14	1.6	6.8	4.9	6.8	.0	35	19	2.5	3.2	82
Jan. 1	Jan. 10	105	36	.3	28	.08	5.0	3.6	8.0	.0	41	10	3.0	4.0	106
Jan. 11	Jan. 18	100	23	.2	26	1.7	9.2	3.5	12	.0	36	21	2.0	5.0	122
Jan. 21	Jan. 31	50	34	.7	15	1.5	8.5	3.5	7.6	.0	25	17	1.5	3.7	89
Feb. 1	Feb. 9	40	15	.4	16	1.2	7.4	2.2	9.6	.0	32	18	2.7	5.0	95
Feb. 11	Feb. 18	40	30	.8	21	2.3	6.1	2.6	12	.0	27	18	1.0	8.0	93
Feb. 19	Feb. 28	50	29	.6	17	2.5	7.0	1.7	11	.0	30	17	1.4	6.0	90
Mar. 1	Mar. 10	.....	.....	.....	.....	.....	.....	.....	.....	.0	.....	.....	.....	.....	.....
Mar. 11	Mar. 20	120	51	.4	19	2.1	7.4	3.5	12	.0	27	19	2.5	7.5	89
Mar. 21	Mar. 31	100	65	.6	18	4.5	7.7	3.3	10	.0	25	19	3.0	6.5	100
Apr. 1	Apr. 10	100	31	.3	20	1.9	9.6	2.8	9.5	.0	37	21	1.5	6.0	118
Apr. 11	Apr. 20	70	27	.4	21	2.6	7.9	2.6	8.7	.0	27	17	1.7	5.8	100
Apr. 21	Apr. 30	90	29	.3	23	2.8	12	2.7	6.5	.0	22	27	1.0	4.5	99
May 1	May 10	.....	.....	.....	.....	.....	.....	.....	.....	.0	.....	.....	.....	.....	.....
May 11	May 20	120	80	.7	11	.74	8.5	2.7	11	.0	27	15	3.0	7.0	83
May 21	May 31	140	27	.2	29	11	11	2.7	6.9	.0	20	18	1.2	7.0	128
June 1	June 10	.....	.....	.....	.....	.....	.....	.....	.....	.0	.....	.....	.....	.....	.....
June 11	June 20	100	71	.7	27	2.8	14	3.2	9.2	.0	35	14	2.4	5.5	117
June 21	June 30	90	70	.8	17	3.2	12	2.7	5.5	.0	51	14	3.0	7.8	100
July 1	July 10	65	25	.4	26	3.2	10	1.9	6.9	.0	44	14	1.6	6.3	116
July 11	July 20	.....	.....	.....	.....	.....	.....	.....	.....	.0	.....	.....	.....	.....	.....
July 21	July 31	35	16	.4	14	1.0	9.8	4.2	6.0	.0	46	14	1.7	7.3	83
Mean.....		72	33	.5	16	1.9	9.0	3.6	8.6	.0	34	16	2.1	5.2	92
Per ct. of anhydrous residue...		.....	.....	.....	20.0	[a]3.4	11.4	4.5	10.8	20.8	.....	20.0	2.6	6.5	.....

[a] Fe_2O_3.

TABLE 20.—*Mineral analyses of water from reservoir near Marion, Ill.*

[Parts per million unless otherwise stated.]

Date (1906–7).		Turbidity.	Suspended matter.	Coefficient of fineness.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.
From—	To—														
Aug. 1	Aug. 10	30	18	0.6	15	0.80	18	12	22	0.0	75	54	0.5	7.7	179
Aug. 11	Aug. 20	135	47	.3	8.0	.14	17	7.1	15	.0	55	40	1.8	8.0	150
Aug. 21	Aug. 30	148	59	.4	5.2	.12	13	7.9	17	.0	43	39	1.0	6.5	113
Aug. 31	Sept. 6	40	27	.7	6.0	.05	16	10	20	.0	51	38	1.7	8.0	127
Sept. 11	Sept. 19	50	16	.3	5.2	.60	14	10	12	.0	62	36	.6	8.0	124
Sept. 20	Sept. 29	20	16	.8	4.8	.10	17	8.4	11	.0	55	35	3.5	8.0	122
Sept. 30	Oct. 8	30	21	.7	7.2	.16	18	7.0	16	.0	46	40	.6	9.0	129
Oct. 14	Oct. 19	10.0	H1	1.1	3.2	.06	18	10	20	.0	62	46	1.0	10	132
Oct. 20	Oct. 31	30	14	.5	11	.30	21	12	20	.0	77	50	.5	11	142
Nov. 1	Nov. 6	20	9.4	.5	26	.05	17	13	18	.0	103	44	1.0	9.5	139
Nov. 9	Nov. 19	60	26	.4	5.0	.12	15	4.9	13	.0	46	43	1.2	7.5	112
Nov. 20	Nov. 22	115	41	.4	16	.70	12	4.3	11	.0	46	30	3.5	4.5	121
Dec. 11	Dec. 14	157	56	.4	18	2.2	16	5.2	21	.0	26	40	1.5	6.5	129
Dec. 25	Dec. 31	174	72	.4	24	2.2	14	11	17	.0	.....	45	2.0	13	174
Jan. 1	Jan. 10	240	81	.4	22	3.6	8.1	2.9	15	.0	45	30	3.0	4.5	124
Jan. 11	Jan. 20	315	160	.5	25	2.5	12	5.2	12	.0	31	42	3.0	5.2	149
Feb. 24	Feb. 27	70	22	.3	21	1.1	17	6.9	18	.0	20	85	1.7	13	172
Mar. 1	Mar. 10	100	73	.7	19	2.0	15	8.9	27	.0	29	74	2.5	9.3	185
Mar. 11	Mar. 20	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Mar. 21	Mar. 31	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Mean		97	43	.5	13	.93	15	8.2	17	.0	51	45	1.7	8.3	140
Per ct. of anhydrous residue		.....	.....	.....	9.6	[a]1.0	11.2	6.1	12.6	18.7	.....	33.4	1.3	6.1	.....

[a] Fe_2O_3.

TABLE 21.—*Mineral analyses of water from reservoir near Cypress, Ill.*

[Parts per million unless otherwise stated.]

Date (1906–7). From—	To—	Turbidity.	Suspended matter.	Coefficient of fineness.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.
Aug. 1	Aug. 10	150	60	0.4	12	0.80	19	11	21	0.0	121	27	0.3	7.7	152
Aug. 11	Aug. 20	125	62	.5	6.2	.14	19	8.8	13	.0	81	29	.7	6.0	122
Aug. 21	Aug. 30	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Aug. 31	Sept. 9	110	37	.3	6.4	.60	17	10	10	.0	78	26	.5	7.0	119
Sept. 10	Sept. 19	100	43	.4	8.6	.10	17	6.5	7.9	.0	75	28	3.4	6.0	132
Sept. 20	Sept. 29	50	38	.8	7.0	.06	18	8.7	13	.0	77	24	.9	7.0	118
Sept. 30	Oct. 9	127	94	.7	14	.35	24	1.8	18	.0	59	64	1.5	9.0	182
Oct. 10	Oct. 19	108	47	.4	25	2.0	20	13	22	.0	62	46	2.5	9.5	187
Oct. 20	Oct. 26	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Oct. 31	Nov. 8	60	30	.5	18	1.1	25	14	19	.0	92	50	1.5	9.5	182
Nov. 9	Nov. 18	70	42	.6	11	.8	24	7.6	18	.0	66	53	3.0	9.5	165
Nov. 21	Nov. 31	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Dec. 2	Dec. 10	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Dec. 12	Dec. 20	290	138	.5	45	4.9	16	6.9	9.1	.0	34	34	2.5	6.5	185
Dec. 21	Dec. 31	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Jan. 1	Jan. 10	620	....	....	37	8.0	10	5.1	13	.0	51	29	4.5	6.5	156
Jan. 11	Jan. 20	270	72	.3	72	13	14	6.1	15	.0	54	37	5.0	4.7	241
Jan. 21	Jan. 31	165	47	.3	45	2.0	14	5.2	14	.0	47	36	2.0	7.2	189
Feb. 1	Feb. 9	100	19	.2	6.0	2.0	7	3.0	11	.0	54	19	3.5	5.3	89
Feb. 10	Feb. 18	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Feb. 19	Feb. 28	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Mar. 1	Mar. 10	90	65	.7	41	8.4	11	5.9	9.8	.0	32	33	3.2	6.8	169
Mar. 11	Mar. 20	450	105	.2	59	7.8	16	5.2	11	.0	47	28	2.3	8.5	207
Mar. 21	Mar. 31	375	46	.1	62	16	14	2.0	13	.0	47	28	3.0	7.5	232
Apr. 1	Apr. 10	55	55	1.0	61	9.1	16	5.3	11	.0	47	38	1.6	6.0	224
Apr. 11	Apr. 20	112	46	.4	43	14	14	5.2	12	.0	47	31	1.7	6.0	182
Apr. 21	Apr. 30	110	26	.2	52	.4	16	5.2	11	.0	42	29	1.8	5.5	205
May 1	May 10	220	72	.3	25	7.41	17	5.8	14	.0	74	40	2.6	6.5	194
May 11	May 20	150	154	1.0	8.6	.52	15	4.6	9.8	.0	57	34	3.4	6.8	124
May 21	May 31	....	....	....	....	....	....	....	....	....	....	....	....	....	....
June 1	June 10	170	123	.7	12	.38	22	9.3	18	.0	64	34	2.2	6.5	164
June 11	June 20	95	66	.7	15	1.3	23	7.9	9.9	.0	79	20	1.0	7.0	149
June 21	June 30	80	36	.4	17	.18	26	6.4	4.3	.0	97	27	2.0	4.8	145
July 1	July 10	30	31	1.0	13	.50	23	5.8	7.4	.0	80	24	2.0	6.0	136
July 11	July 20	30	17	.6	7.2	.18	25	6.4	6.3	.0	97	26	1.3	5.5	137
July 21	July 31	30	16	.5	8.4	.41	27	7.4	11	.0	104	26	1.4	6.0	140
Mean		155	59	.5	29	3.7	18	7.0	13	.0	67	33	2.2	6.8	165
Per ct. of anhydrous residue		..	.	.....	19.7	[a]3.6	12.2	4.8	8.8	22.4	.....	22.4	1.5	4.6	....

[a] Fe_2O_3.

TABLE 22.—*Mineral analyses of water from reservoir near Joppa, Ill.*

[Parts per million unless otherwise stated.]

Date (1906–7). From—	To—	Turbidity.	Suspended matter.	Coefficient of fineness.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.
Aug. 1	Aug. 10	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Aug. 11	Aug. 20	135	43	0.3	15	0.7	7.4	6.6	10.0	0.0	46	16	2.7	4.5	98
Aug. 21	Aug. 30	140	49	.4	9.8	.30	8.7	4.4	11	.0	43	15	3.0	6.5	96
Aug. 31	Sept. 7	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Sept. 14	Sept. 19	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Sept. 20	Sept. 29	40	26	.6	8.2	.30	12	5.3	9.9	.0	56	14	3.0	5.0	87
Sept. 30	Oct. 9	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Oct. 10	Oct. 19	40	22	.6	9.4	.15	14	8.3	8.8	.0	58	14	3.0	4.0	94
Oct. 20	Oct. 29	40	25	.6	13	.6	16	6.7	14	.0	70	20	2.0	4.5	102
Oct. 30	Nov. 8	80	36	.4	19	.6	14	5.8	13	.0	77	22	1.8	4.3	127
Nov. 9	Nov. 19	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Nov. 20	Nov. 30	80	30	.4	15	1.2	14	4.2	10	.0	49	24	1.5	3.5	96
Dec. 1	Dec. 10	70	23	.3	20	3.0	8.5	3.8	14	.0	56	20	1.5	3.2	104
Dec. 11	Dec. 20	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Dec. 22	Dec. 31	128	46	.4	29	3.2	9.2	4.9	11	.0	52	18	.....	.....	121
Jan. 1	Jan. 10	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Jan. 11	Jan. 20	164	87	.5	33	4.4	7.0	3.0	12	.0	41	24	1.2	3.7	129
Jan. 21	Jan. 31	188	43	.2	32	6.5	9.6	0.87	12	.0	25	20	2.5	4.5	133
Feb. 1	Feb. 9	135	21	.2	31	4.2	6.8	4.8	7.6	.0	42	18	3.0	4.0	112
Feb. 10	Feb. 18	90	22	.2	34	6.4	7.4	2.6	6.2	.0	37	9.7	6.0	7.0	129
Feb. 19	Feb. 28	70	33	.5	28	3.2	7.0	2.4	13	.0	27	23	1.2	4.7	110
Mar. 1	Mar. 10	90	46	.5	32	8.4	17	3.0	4.9	.0	25	24	1.2	3.0	130
Mar. 11	Mar. 20	145	88	.6	35	7.8	6.6	5.5	9.5	.0	37	39	1.4	4.8	138
Mar. 21	Mar. 31	130	32	.2	28	7.8	10	0.86	9.5	.0	27	22	2.3	4.2	163
Apr. 1	Apr. 10	120	32	.3	56	7.6	10	3.5	7.6	.0	25	19	1.2	3.4	158
Apr. 11	Apr. 20	120	48	.4	40	9.9	7.9	3.3	7.1	.0	40	16	0.9	3.5	129
Apr. 21	Apr. 30	115	71	.6	8.0	5.6	10.0	4.0	5.4	.0	30	29	0.8	3.5	130
May 2	May 10	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
May 11	May 20	112	95	.8	19	1.9	7.0	2.1	6.8	.0	22	19	1.6	3.8	89
May 21	May 31	120	116	1.0	10	.95	14	3.7	9.3	.0	30	18	1.3	5.8	72
June 1	June 10	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
June 11	June 20	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
June 21	June 30	170	160	.9	11	.34	9.4	4.8	7.0	.0	66	16	0.3	3.0	74
July 1	July 10	300	318	1.1	15	1.6	10.0	2.6	5.5	.0	49	14	0.6	4.8	82
July 11	July 20	100	131	1.3	7.8	.44	12	2.7	2.5	.0	49	14	0.6	6.0	73
July 21	July 31	95	87	.9	19	3.2	12	4.8	6.8	.0	41	14	3.0	3.5	99
Mean		116	66	.5	22	3.5	10	4.0	9.0	.0	43	19	1.9	4.3	111
Per ct. of anhydrous residue		.....	.....	.....	22.8	[a]5.2	10.4	4.1	9.3	22.0	.....	19.7	2.0	4.5	.....

[a] Fe_2O_3.

TABLE 23.—*Mineral analyses of water from Rock River near Rockford, Ill.*

[Parts per million unless otherwise stated.]

Date (1906–7).		Turbidity.	Suspended matter.	Coefficient of fineness.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.
From—	To—														
Aug. 1	Aug. 10	450	198	0.4	14	0.20	32	19	11	0.0	187	17	3.0	5.5	207
Aug. 11	Aug. 20	228	115	.5	22	.24	29	21	11	.0	174	21	3.6	2.5	198
Aug. 21	Aug. 30	310	142	.4	19	1.7	28	17	11	.0	161	16	2.5	6.0	179
Aug. 31	Sept. 9	148	78	.5	20	.12	40	26	7.9	.0	253	22	3.5	4.5	249
Sept. 10	Sept. 19	140	65	.5	6.6	.50	41	22	11	.0	272	18	3.6	4.5	229
Sept. 20	Sept. 29	60	34	.6	15	.08	54	33	18	.0	295	15	4.0	5.5	275
Sept. 30	Oct. 8	60	43	.7	8.8	.04	44	26	10.0	.0	252	16	4.0	4.5	243
Oct. 10	Oct. 18	30	19	.6	13	.07	52	26	13	.0	315	17	4.0	5.0	296
Oct. 20	Oct. 29	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Nov. 1	Nov. 8	20	11	.6	13	.05	53	33	12	.0	320	19	5.0	4.5	286
Nov. 10	Nov. 19	10.0	4.0	.4	11	.04	55	32	7.5	.0	314	21	3.5	6.0	287
Nov. 20	Nov. 29	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Dec. 1	Dec. 10	20	17	.9	13	.07	48	32	9.5	.0	291	21	4.0	5.2	256
Dec. 11	Dec. 20	15	6.4	.4	12	.13	52	32	13	.0	310	25	4.0	7.5	295
Dec. 21	Dec. 31	10.0	16	1.6	18	.14	57	34	14	.0	347	34	4.0	5.5	320
Jan. 1	Jan. 10	380	150	.4	21	1.5	35	19	16	.0	184	28	4.0	3.5	218
Jan. 11	Jan. 20	290	354	1.2	18	.8	32	18	10	.0	218	30	4.0	4.0	228
Jan. 21	Jan. 31	177	96	.5	17	1.2	28	14	11	.0	139	17	3.0	5.0	173
Feb. 1	Feb. 7	50	31	.6	22	.7	39	23	12	.0	234	30	3.5	5.0	243
Feb. 10	Feb. 18	40	23	.6	18	.26	46	25	9.0	.0	265	21	5.5	5.5	261
Feb. 19	Feb. 28	80	39	.5	13	1.8	34	17	9.2	.0	176	19	4.5	6.0	194
Mar. 1	Mar. 10	20	16	.8	13	.25	44	26	7.9	.0	227	22	7.0	5.8	233
Mar. 11	Mar. 20	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Mar. 21	Mar. 31	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Apr. 1	Apr. 10	270	270	1.0	16	.39	41	20	7.6	.0	208	24	2.8	2.8	223
Apr. 11	Apr. 20	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Apr. 21	Apr. 30	35	24	.7	8.0	.16	50	36	4.8	.0	264	24	2.5	5.0	266
May 1	May 10	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
May 11	May 20	40	45	1.1	9.2	.15	52	22	8.2	.0	292	25	9.0	3.0	306
May 21	May 31	70	75	1.1	8.8	.15	51	27	11	.0	287	23	3.2	4.0	268
June 1	June 10	80	70	.9	8.6	.26	53	29	8.2	.0	267	25	3.6	3.0	268
June 11	June 20	100	107	1.1	8.8	.18	57	33	7.7	.0	272	25	4.0	3.0	275
June 21	June 30	110	101	.9	15	.17	62	29	9.2	.0	287	19	3.0	3.5	283
July 1	July 10	210	192	.9	21	.78	51	20	7.6	.0	260	18	6.0	2.5	243
July 11	July 20	240	179	.7	18	.54	53	24	7.2	.0	253	13	6.0	3.0	239
July 21	July 31	340	241	.7	28	.38	48	24	11	.0	226	20	2.5	6.0	247
Mean		134	92	.7	15	.44	45	25	10	.0	252	22	4.1	4.6	250
Per ct. of anhydrous residue		.....	.....	.....	6.0	[a].2	18.0	10.0	4.0	49.6	.....	8.8	1.6	1.8	.....

[a] Fe_2O_3.

TABLE 24.—*Mineral analyses of water from Rock River near Sterling, Ill.*

[Parts per million unless otherwise stated.]

Date (1906–7).		Turbidity.	Suspended matter.	Coefficient of fineness.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.
From—	To—														
Aug. 1	Aug. 10	600	422	0.7	11	0.20	40	25	14	0.0	225	18	6.0	5.7	247
Aug. 11	Aug. 20	425	321	.8	23	.12	30	18	13	.0	158	18	3.3	7.7	187
Aug. 21	Aug. 30	565	402	.7	23	2.4	30	17	9.7	.0	153	13	3.5	4.5	183
Aug. 31	Sept. 9	410	343	.8	20	.12	49	31	6.2	.0	264	19	3.5	5.0	268
Sept. 11	Sept. 17	600	463	.7	17	.30	47	23	15	.0	278	19	2.0	6.0	265
Sept. 20	Sept. 29	290	281	1.0	13	.10	50	31	5.7	.0	285	17	4.0	5.5	265
Sept. 30	Oct. 7	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Oct. 11	Oct. 18	144	127	.9	13	.03	55	26	7.7	.0	312	22	3.5	10	297
Oct. 20	Oct. 28	216	168	.8	13	.03	56	34	10	.0	330	18	3.0	5.5	303
Nov. 1	Nov. 8	100	112	1.1	20	.10	55	34	18	.0	326	30	3.0	6.5	301
Nov. 10	Nov. 16	30	21	.7	6.8	.03	53	32	10	.0	330	24	0.4	7.0	288
Nov. 20	Nov. 29	60	49	.8	13	.03	55	37	10	.0	303	26	5.0	5.0	280
Dec. 1	Dec. 10	50	115	2.3	17	.04	52	32	9.2	.0	293	26	2.5	6.2	275
Dec. 11	Dec. 20	50	666	13	8.8	.06	56	35	15	.0	.....	33	.....	.....	304
Dec. 21	Dec. 31	20	28	1.4	12	.22	54	29	16	.0	350	21	5.0	6.5	337
Jan. 1	Jan. 10	280	307	1.1	10	.20	37	24	14	.0	227	26	4.5	5.0	252
Jan. 11	Jan. 19	187	111	.6	26	.56	41	24	13	.0	245	36	4.0	3.5	273
Jan. 21	Jan. 30	210	146	.5	16	1.3	29	14	18	.0	139	24	5.0	5.2	176
Feb. 1	Feb. 7	45	42	.9	17	.64	57	31	22	.0	285	40	1.8	11	312
Feb. 12	Feb. 17	40	31	.8	9.6	.40	48	27	12	.0	235	44	4.5	16	270
Feb. 19	Feb. 28	60	54	.9	12	.13	42	21	15	.0	213	26	5.5	5.3	224
Mar. 2	Mar. 10	60	50	.8	15	.21	46	26	13	.0	.....	24	6.5	4.0	276
Mar. 11	Mar. 20	90	44	.5	20	.14	59	28	17	.0	278	25	0.3	7.5	282
Mar. 21	Mar. 31	110	51	.5	15	.26	49	21	12	.0	245	19	5.4	3.8	260
Apr. 1	Apr. 10	240	178	.7	15	.46	46	22	19	.0	240	31	4.6	2.8	242
Apr. 11	Apr. 20	80	56	.7	16	.20	48	26	11	.0	242	29	3.7	3.5	260
Apr. 21	Apr. 30	75	69	.9	9.6	.32	51	36	6.9	.0	269	29	2.4	5.0	280
May 1	May 10	55	54	1.0	16	.13	51	21	9.8	.0	282	29	6.0	3.0	294
May 11	May 20	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
May 21	May 31	285	277	1.0	9.0	.15	50	29	11	.0	262	29	3.8	3.5	260
June 1	June 10	385	606	.7	13	.57	50	28	9.7	.0	267	27	3.7	3.3	271
June 11	June 20	200	233	1.1	14	.32	62	31	10	.0	289	21	5.0	3.0	299
June 21	June 30	220	127	.6	18	.25	62	29	10	.0	314	22	3.6	5.0	287
July 1	July 10	475	481	1.0	13	.30	52	24	6.6	.0	277	19	5.0	3.0	253
July 11	July 20	500	969	1.9	17	.14	52	21	7.3	.0	248	21	2.6	3.5	244
July 21	July 31	618	608	1.0	24	.19	53	25	10	.0	255	18	1.7	5.0	255
Mean		229	236	1.2	15	.31	49	27	12	.0	263	25	3.8	5.5	267
Per ct. of anhydrous residue		.....	.....	.....	5.6	a.2	18.3	10.1	4.5	48.4	.....	9.4	1.4	2.1	....

a Fe_2O_3.

TABLE 25.—*Mineral analyses of water from Kankakee River near Kankakee, Ill.*

[Parts per million unless otherwise stated.]

Date (1906–7). From—	To—	Turbidity.	Suspended matter.	Coefficient of fineness.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.
Aug. 4	Aug. 10	30	13	0.4	22	0.20	58	21	18	0.0	218	69	4.0	4.7	329
Aug. 11	Aug. 18	40	7.6	.2	16	.10	56	20	8.5	.0	213	53	3.0	5.5	273
Aug. 21	Aug. 30	70	28	.4	21	.07	54	21	17	.0	218	57	3.5	3.5	326
Aug. 31	Sept. 9	50	26	.5	17	.14	57	24	14	.0	201	52	2.0	4.5	283
Sept. 10	Sept. 19	10.0	16	1.5	14	.12	55	27	12	.0	226	56	0.6	5.0	289
Sept. 20	Sept. 29	30	13	.4	12	.15	58	18	16	.0	226	38	1.8	5.5	286
Oct. 1	Oct. 8	50	40	.8	16	.06	58	22	16	.0	225	53	2.0	5.0	285
Oct. 11	Oct. 19	20	14	.7	11	.04	61	.....	12	.0	250	60	1.7	6.0	300
Oct. 21	Oct. 29	30	19	.6	15	.06	63	27	17	.0	262	63	1.0	8.0	302
Oct. 30	Nov. 8	10.0	4.5	.4	17	.03	64	24	13	.0	263	62	0.6	4.8	306
Nov. 9	Nov. 19	30	18	.6	11	.04	55	16	10	.0	219	74	4.0	6.5	295
Nov. 20	Nov. 30	20	19	1.0	16	.05	61	23	22	.0	203	83	8.0	6.0	314
Dec. 1	Dec. 10	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Dec. 11	Dec. 14	10.0	19	1.9	17	.34	55	31	25	.0	180	90	8.0	10	312
Dec. 21	Dec. 30	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Dec. 31	Jan. 9	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Jan. 12	Jan. 12	50	38	.8	19	.44	42	16	11	.0	169	65	8.0	4.2	253
Jan. 13	Jan. 25	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Jan. 26	Feb. 7	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Feb. 8	Feb. 18	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Feb. 19	Feb. 28	20	34	1.7	15	.19	56	16	11	.0	195	68	3.2	5.5	293
Mar. 1	Mar. 10	25	6.5	.3	10	.36	52	20	14	.0	185	71	4.0	3.3	266
Mar. 11	Mar. 20	160	49	.3	15	.39	55	18	11	.0	190	73	4.6	3.0	304
Mar. 21	Mar. 31	190	108	.6	19	.46	58	17	11	.0	195	61	4.0	4.0	286
Apr. 1	Apr. 10	30	21	.7	16	.61	45	16	12	.0	181	43	4.0	4.2	247
Apr. 11	Apr. 20	12	6.4	.5	12	.41	51	17	8.7	.0	188	42	3.6	3.5	220
Apr. 21	Apr. 30	15	12	.8	11	.30	63	27	9.3	.0	218	65	2.4	3.5	293
May 1	May 10	90	43	.5	10	.25	51	17	9.3	.0	183	53	8.8	4.0	255
May 11	May 20	25	16	.6	7.2	.20	54	22	9.0	.0	202	55	6.2	4.0	285
May 21	May 31	30	29	1.0	8.4	.34	61	23	10	.0	219	58	3.2	3.5	310
June 1	June 10	80	73	.9	19	.68	58	21	11	.0	210	58	7.2	3.0	289
June 11	June 20	35	28	.8	8.8	.22	70	19	9.6	.0	223	40	4.0	4.5	293
June 21	June 30	110	102	.9	19	.45	76	23	6.8	.0	273	42	3.2	3.0	299
July 1	July 10	45	43	1.0	15	.32	71	25	8.2	.0	258	46	3.5	3.0	312
July 11	July 20	138	103	.7	16	.74	52	18	5.5	.0	198	34	6.8	2.5	237
July 21	July 31	60	44	.8	17	.34	69	25	8.7	.0	253	46	6.6	4.0	294
Mean		50	32	.7	15	.27	58	21	12	.0	215	57	4.1	4.9	288
Per ct. of anhydrous residue		.....	.....	.....	5.4	[a].1	20.8	7.5	4.3	38.1	.....	20.5	1.5	1.8	....

[a] Fe_2O_3.

TABLE 26.—*Mineral analyses of water from Fox River near Elgin, Ill.*

[Parts per million unless otherwise stated.]

Date (1906–7).		Turbidity.	Suspended matter.	Coefficient of fineness.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.
From—	To—														
Aug. 3	Aug. 10	110	39	0.4	26	0.20	42	36	11	0.0	283	27	2.5	6.0	304
Aug. 11	Aug. 20	30	8.4	.3	15	.10	40	35	10	.0	240	31	3.4	4.7	270
Aug. 21	Aug. 30	50	30	.6	10	.06	44	34	19	.0	252	31	3.0	7.0	280
Aug. 31	Sept. 8	50	7.0	.1	12	.05	41	34	17	.0	291	29	1.2	6.5	264
Sept. 11	Sept. 19	50	31	.6	9.4	.20	32	35	14	.0	260	29	1.8	5.0	234
Sept. 20	Sept. 29	40	30	.8	9.4	.03	43	29	10	.0	273	24	2.0	6.5	265
Sept. 30	Oct. 9	40	20	.5	7.0	.03	43	34	11	.0	254	49	1.7	5.0	252
Oct. 10	Oct. 18	20	15	.8	5.8	.08	42	35	7.7	.0	270	31	1.2	5.5	265
Oct. 20	Oct. 29	30	21	.7	8.2	.05	51	37	19	.0	300	33	0.6	7.2	285
Nov. 1	Nov. 8	20	10.0	.5	10	.04	51	35	10	.0	316	36	1.5	7.5	306
Nov. 9	Nov. 19	10.0	4.4	.4	6.0	.03	50	33	13	.0	310	36	1.2	5.5	289
Nov. 20	Nov. 30	15	13	.9	8.6	.03	57	37	14	.0	300	45	3.0	7.0	293
Dec. 1	Dec. 10	10.0	5.2	.5	11	.06	55	27	12	.0	300	51	4.0	7.5	315
Dec. 11	Dec. 20	10.0	24	.2	10	.13	62	37	8.8	.0	309	46	2.5	6.5	348
Dec. 21	Dec. 31	5.0	9.6	.2	9.2	.12	65	39	13	.0	365	53	3.5	5.5	373
Jan. 1	Jan. 10	40	18	.4	20	.07	61	20	18	.0	309	51	3.5	6.0	378
Jan. 11	Jan. 20	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Jan. 21	Jan. 31	50	27	.5	14	.64	45	22	10	.0	188	42	2.5	7.0	249
Feb. 1	Feb. 9	15	10.0	.7	14	.20	53	30	10	.0	250	49	3.0	6.2	310
Feb. 10	Feb. 18	7.0	8.4	1.2	15	.13	56	31	8.4	.0	231	42	4.0	6.0	317
Feb. 19	Feb. 28	15	9.6	.6	12	.13	44	23	14	.0	220	44	4.0	6.5	265
Mar. 1	Mar. 10	5.0	6.4	1.3	11	.36	45	26	13	.0	232	38	2.7	4.3	274
Mar. 11	Mar. 20	10.0	9.8	1.0	12	.27	55	21	10	.0	245	40	1.7	5.0	277
Mar. 21	Mar. 31	25	12	.5	11	.15	48	23	7.7	.0	235	45	1.5	5.5	258
Apr. 1	Apr. 10	25	23	1.0	10	.13	54	25	7.4	.0	256	35	1.7	5.5	277
Apr. 11	Apr. 20	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Apr. 21	Apr. 30	25	21	.8	10	.28	55	34	11	.0	267	43	2.4	2.3	292
May 1	May 10	20	15	.8	11	.12	54	22	10	.0	247	48	2.5	4.0	304
May 11	May 20	35	40	1.4	20	.20	56	23	9.0	.0	292	47	2.6	3.3	329
May 21	May 31	55	55	1.0	12	.12	52	29	5.5	.0	234	50	2.0	3.5	273
June 1	June 10	35	35	1.0	11	.19	56	24	5.8	.0	247	35	2.5	3.3	292
June 11	June 20	80	45	.6	9.2	.25	61	29	8.4	.0	265	32	1.5	3.5	281
June 21	June 30	80	53	.7	16	.30	64	33	5.1	.0	272	29	3.5	3.0	308
July 1	July 10	50	55	1.1	12	.15	56	31	10	.0	275	28	2.0	4.5	291
July 11	July 20	55	50	.9	12	.17	56	27	8.7	.0	272	35	2.7	2.5	284
July 21	July 31	35	31	.9	17	.17	56	29	6.6	.0	273	26	2.0	3.3	269
Mean		34	23	.7	12	.15	51	30	11	.0	268	38	2.4	5.2	290
Per ct. of anhydrous residue		.....	.....	.....	4.3	[a].1	18.1	10.6	3.9	46.8	.....	13.5	0.9	1.8	....

[a] Fe_2O_3.

TABLE 27.—*Mineral analyses of water from Fox River near Ottawa, Ill.*

[Parts per million unless otherwise stated.]

Date (1906–7).		Turbidity.	Suspended matter.	Coefficient of fineness.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.
From—	To—														
Aug. 2	Aug. 10	135	91	0.7	13	0.15	47	35	20	0.0	278	45	3.0	12	335
Aug. 11	Aug. 20	345	237	.7	13	.14	41	34	20	.0	246	50	3.3	16	293
Aug. 21	Aug. 30	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Aug. 31	Sept. 9	105	78	.7	5.0	.07	45	39	17	.0	257	43	2.7	9.5	298
Sept. 10	Sept. 19	40	63	1.6	6.1	.10	43	32	18	.0	275	50	2.4	12	288
Sept. 20	Sept. 29	30	54	1.8	6.8	.09	49	36	10.0	.0	261	43	2.5	10	287
Sept. 30	Oct. 9	155	123	.8	9.4	.06	55	31	19	.0	254	53	5.0	8.0	307
Oct. 10	Oct. 19	20	14	.7	4.2	.07	55	36	15	.0	290	61	2.0	11	334
Oct. 20	Oct. 28	10.0	7.0	.7	7.2	.06	60	39	21	.0	320	60	1.0	12	349
Oct. 30	Nov. 8	20	6.0	.3	8.6	.06	60	39	17	.0	330	54	1.5	8.0	351
Nov. 9	Nov. 19	10.0	3.4	.3	4.6	.02	60	40	10	.0	320	56	0.6	9.0	332
Nov. 21	Nov 30	40	42	1.0	12	.07	67	37	13	.0	298	72	6.0	7.0	348
Dec. 1	Dec. 9	20	19	1.0	11	.11	65	36	9.5	.0	315	68	3.0	7.5	357
Dec. 12	Dec. 20	15	16	1.0	9.2	.19	72	39	12	.0	311	75	6.5	8.3	376
Dec. 21	Dec. 31	40	54	1.4	13	.16	71	40	15	.0	351	82	5.5	8.7	409
Jan. 1	Jan. 10	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Jan. 11	Jan. 20	310	241	.8	31	.40	52	25	15	.0	238	58	8.0	5.0	305
Jan. 21	Jan. 30	40	23	.6	21	.40	46	23	16	.0	204	49	7.0	5.0	273
Feb. 1	Feb. 9	10.0	10.0	1.0	7.8	.09	58	31	13	.0	251	64	5.5	6.5	334
Feb. 10	Feb. 18	7.0	8.0	1.1	16	.15	59	31	12	.0	268	57	6.5	7.5	329
Feb. 19	Feb. 28	5.0	11	2.2	12	.05	63	24	15	.0	244	70	4.6	8.2	319
Mar. 1	Mar. 10	50	73	1.5	8.8	.09	60	29	16	.0	230	78	5.4	6.0	372
Mar. 11	Mar. 20	30	48	1.6	11	.22	64	29	8.2	.0	262	80	4.0	13	322
Mar. 21	Mar. 31	10.0	43	4.3	8.0	.15	61	18	15	.0	250	71	6.0	8.2	336
Apr. 1	Apr. 10	30	36	1.2	12	.19	63	30	9.3	.0	257	69	6.0	3.3	331
Apr. 11	Apr. 20	20	13	1.6	21	.92	62	23	35	.0	276	66	5.0	5.0	367
Apr. 21	Apr. 31	15	15	1.0	7.0	.22	60	29	9.3	.0	264	56	3.8	5.0	314
May 1	May 10	15	15	1.0	8.2	.17	62	22	17	.0	287	63	4.0	6.0	343
May 11	May 20	15	35	2.3	9.4	.43	58	26	8.7	.0	284	54	4.0	5.0	344
May 21	May 31	200	197	1.0	16	.32	66	36	14	.0	.....	55	5.0	3.8	360
June 1	June 10	90	81	.9	11	.28	61	31	12	.0	257	63	8.8	6.0	326
June 11	June 20	95	93	1.0	8.8	.26	67	31	8.4	.0	272	50	3.0	5.0	319
June 21	June 30	218	125	.6	9.2	.19	71	31	5.5	.0	280	49	9.0	5.0	326
July 1	July 10	550	542	1.0	16	.37	61	27	7.9	.0	277	45	5.0	5.0	307
July 11	July 20	300	366	1.2	17	.22	72	30	8.5	.0	286	60	10	6.0	379
July 21	July 31	192	173	.9	13	.38	85	38	9.3	.0	287	95	12	14	416
Mean		94	87	1.2	11	.20	60	32	14	.0	275	61	4.9	7.9	335
Per ct. of anhydrous residue		.....	.....	.....	3.4	*a* .1	18.4	9.8	4.3	41.4	.....	18.7	1.5	2.4	....

a Fe_2O_3.

TABLE 28.—*Mineral analyses of water from Vermilion River near Streator, Ill.*

[Parts per million unless otherwise stated.]

Date (1906-7).		Turbidity.	Suspended matter.	Coefficient of fineness.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.
From—	To—														
Aug. 1	Aug. 10	40	22	0.6	23	0.10	44	36	27	0.0	248	72	2.5	10	357
Aug. 11	Aug. 20	30	16	.5	13	.10	40	35	23	.0	247	74	2.1	14	321
Aug. 21	Aug. 30	50	29	.6	10	.60	39	33	16	.0	198	64	2.5	13	280
Aug. 31	Sept. 9	60	48	.8	15	.24	39	28	.....	.0	165	57	2.5	6.0	243
Sept. 10	Sept. 19	20	15	.8	9.6	.14	36	28	18	.0	198	56	1.6	5.0	247
Sept. 20	Sept. 29	40	26	.6	11	.16	43	23	18	.0	205	56	1	8.0	254
Sept. 31	Oct. 9	50	38	.8	5.8	.20	37	23	20	.0	190	53	1	7	240
Oct. 10	Oct. 18	20	23	.1	4.6	.05	41	28	22	.0	212	66	1.7	10	268
Oct. 22	Oct. 29	20	13	.6	9.0	.05	47	28	24	.0	260	60	1.2	10	294
Oct. 30	Nov. 8	20	11	.6	9.0	.03	49	34	23	.0	213	69	.3	9.3	309
Nov. 9	Nov. 19	20	10	.5	11	.02	48	33	20	.0	254	70	.3	10.0	322
Nov. 20	Nov. 30	60	36	.6	17	.10	55	31	18	.0	260	64	7	9.3	317
Dec. 2	Dec. 10	110	56	.5	11	.17	61	30	23	.0	280	68	8	5.5	333
Dec. 11	Dec. 20	30	33	1.1	15	.14	63	32	18	.0	274	69	16	4.5	351
Dec. 21	Dec. 31	20	23	1.1	17	.12	67	34	21	.0	329	86	10	5.7	397
Jan. 1	Jan. 10	280	122	.4	28	.52	56	28	30	.0	257	68	16	4.0	367
Jan. 11	Jan. 20	335	235	.7	19	.72	55	26	14	.0	239	69	14	4.7	340
Jan. 21	Jan. 31	315	194	.6	20	.36	46	20	13	.0	175	56	14	5.7	285
Feb. 1	Feb. 9	25	14	.6	17	.17	69	33	18	0	278	83	16	7	402
Feb. 10	Feb. 18	40	30	.8	9.4	.22	62	29	13	0	247	80	18	7.7	359
Feb. 19	Feb. 28	50	34	.7	14	.09	57	29	21	0	238	74	17	6.5	335
Mar. 1	Mar. 10	100	64	.6	12	.32	69	22	20	0	245	76	24	8.3	342
Mar. 11	Mar. 20	260	87	.3	19	.30	55	20	11	0	217	55	14	6.5	335
Mar. 21	Mar. 31	150	68	.4	28	.22	57	22	22	.0	245	86	28	6.5	363
Apr. 1	Apr. 10	35	37	1.0	19	.16	60	30	13	.0	250	46	26	3.8	339
Apr. 11	Apr. 20	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Apr. 21	Apr. 30	35	28	.8	9.8	.12	62	38	8.9	.0	256	77	19	5.5	333
May 1	May 10	100	49	.5	16	.14	60	24	8.7	.0	237	72	4.8	4.5	351
May 11	May 20	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
May 21	May 31	80	78	1.0	11	.34	62	31	20	.0	247	80	22	6.3	340
June 1	June 10	45	32	.7	9.2	.26	62	35	17	.0	255	70	28	4	356
June 11	June 20	55	44	.8	9.4	.08	74	37	12	.0	276	76	20	4	368
June 21	June 30	85	79	.9	13	.21	70	29	14	.0	262	66	14	5	329
July 1	July 10	420	415	1.0	16	.25	61	25	16	.0	241	69	13	6	326
July 11	July 20	560	570	1.0	19	.50	50	21	10	.0	200	50	12	5	273
July 21	July 31	70	63	.9	20	.22	78	37	12	.0	300	70	20	6.5	388
Mean		107	78	.7	14	.22	55	29	18	.0	241	68	12	6.9	325
Per ct. of anhydrous residue		.....	.....	.....	4.4	[a].1	17.1	9.0	5.6	36.9	.....	21.1	3.7	2.1	.....

[a] Fe_2O_3.

TABLE 29.—*Mineral analyses of water from Sangamon River near Decatur, Ill.*

[Parts per million unless otherwise stated.]

Date (1906–7).		Turbidity.	Suspended matter.	Coefficient of fineness.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.	Mean gage height (feet).
From—	To—															
Aug 1	Aug. 10	240	107	0.4	26	0.2	46	21	15	0.0	223	20	4.5	8.2	262	....
Aug. 11	Aug. 20	260	121	.5	20	.2	46	20	48.8	.0	214	23	4.8	3.5	233	....
Aug. 21	Aug. 30	270	106	.5	18	.06	53	22	8.5	.0	235	25	4.0	2.7	264	....
Aug. 31	Sept. 9	117	51	.4	17	.09	61	27	13	.0	305	26	4.0	4.5	297	....
Sept. 10	Sept. 19	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	....
Sept. 21	Sept. 29	70	43	.6	15	.03	55	24	18	.0	315	22	2.5	10	302	....
Oct. 1	Oct. 9	60	40	.7	12	.05	54	30	15	.0	283	26	3.0	5.5	286	....
Oct. 10	Oct. 19	20	13	.6	10	.15	53	30	21	.0	297	27	2.5	5.0	275	....
Oct. 20	Oct. 29	50	33	.7	11	.06	64	35	20	.0	353	21	1.0	9.0	332	....
Nov. 1	Nov. 8	30	19	.6	15	.10	67	44	19	.0	380	33	1.0	7.8	338	....
Nov. 9	Nov. 17	20	13	.6	11	.02	50	28	15	.0	360	25	0.9	8.5	324	....
Nov. 20	Nov. 30	168	104	.6	16	.14	52	25	12	.0	240	39	8.0	3.5	274	....
Dec. 1	Dec. 10	196	110	.6	17	.40	51	28	13	.0	278	37	7.0	5.5	283	....
Dec. 11	Dec. 20	30	27	.9	29	.16	58	30	21	.0	285	36	6.0	5.5	316	....
Dec. 22	Dec. 31	25	31	1.2	15	.28	62	30	12	.0	314	42	8.0	7.0	332	....
Jan. 1	Jan. 10	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	8.2
Jan. 11	Jan. 20	240	144	.6	36	.74	45	20	17	.0	227	64	7.0	3.5	291	10.0
Jan. 21	Jan. 31	220	85	.4	40	1.9	42	18	15	.0	186	42	8.0	5.5	279	12.2
Feb. 1	Feb. 8	20	20	1.0	23	.13	59	28	15	.0	290	43	12	5.2	319	6.9
Feb. 11	Feb. 18	25	22	.9	22	.07	59	22	15	.0	231	40	10	8.0	317	6.0
Feb. 20	Feb. 27	20	22	1.0	21	.16	60	27	15	.0	290	37	8.0	6.5	317	6.0
Mar. 1	Mar. 10	20	19	1.0	14	.15	57	29	15	.0	.....	40	14	5.0	325	5.9
Mar. 11	Mar. 20	410	336	.8	30	.30	45	20	14	.0	192	32	8.0	5.5	210	10.6
Mar. 21	Mar. 31	100	43	.4	20	.22	53	27	15	.0	267	45	12	4.5	305	7.5
Apr. 1	Apr. 10	40	36	.9	18	.19	58	26	11	.0	268	42	14	7.3	287	6.9
Apr. 11	Apr. 20	10	10	1.0	15	.23	47	18	11	.0	252	42	.....	4.5	292	5.7
Apr. 21	Apr. 30	30	26	.9	13	.25	55	32	9.5	.0	265	46	11	3.2	286	5.5
May 1	May 10	100	62	.6	17	.18	55	24	9.8	.0	247	46	18	5.5	292	6.4
May 11	May 20	60	49	.8	12	.15	54	28	12	.0	271	38	19	5.5	288	6.2
May 21	May 31	140	128	.9	19	.46	64	30	9.8	.0	.....	37	12	3.7	336	8.6
June 1	June 10	95	88	.9	16	.30	53	24	14	.0	.....	23	20	4.3	292	8.4
June 11	June 20	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	7.6
June 21	June 30	340	318	.9	19	.60	54	21	7.7	.0	218	26	14	2.0	240	7.3
July 1	July 10	90	63	.7	20	.16	71	28	10	.0	287	29	9.0	5.0	334	5.8
July 11	July 20	425	435	1.0	18	.56	47	16	8.2	.0	197	22	7.0	4.0	230	7.4
July 21	July 31	210	156	.7	21	.32	63	24	17	.0	280	45	12	4.3	326	7.4
Mean.....		126	87	.7	19	.27	55	26	14	.0	268	35	8.5	5.4	293	....
Per ct. of anhydrous residue..		.....	.....	.....	6.4	[a].1	18.7	8.8	4.7	44.7	.....	11.9	2.9	1.8	.....	....

[a] Fe_2O_3.

TABLE 30.—*Mineral analyses of water from Sangamon River near Springfield, Ill.*

[Parts per million unless otherwise stated.]

Date (1906-7).		Turbidity.	Suspended matter.	Coefficient of fineness.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.
From—	To—														
Aug. —	Aug. 10	180	64	0.4	17	0.10	44	24	19	0.0	.....	27	4.0	9.7	275
Aug. 11	Aug. 20	248	122	.5	18	.80	36	18	13	.0	192	24	4.2	5.2	222
Aug. 21	Aug. 30	320	123	.4	17	1.40	41	24	16	.0	192	26	4.0	8.5	228
Aug. 31	Sept. 9	163	77	.5	20	.15	51	28	4.9	.0	203	34	3.0	7.0	284
Sept. 10	Sept. 19	70	39	.6	12	.50	48	22	17	.0	294	28	2.8	10	271
Sept. 20	Sept. 29	30	22	.7	9.6	.05	44	23	16	.0	225	24	1.3	8.5	223
Sept. 30	Oct. 6	100	45	.4	9.4	.10	51	24	15	.0	250	36	2.0	14	272
Oct. 11	Oct. 19	40	17	.5	21	.10	47	28	25	.0	289	33	2.0	8.5	277
Oct. 20	Oct. 28	20	6.6	.3	9.6	.05	57	33	20	.0	307	33	0.20	10	291
Oct. 30	Nov. 8	10.0	4.6	.5	19	.05	59	29	19	.0	315	36	0.10	11	311
Nov. 11	Nov. 19	20	5.2	.3	7.2	.10	62	32	14	.0	320	36	0.30	13	315
Nov. 21	Nov. 30	182	122	.7	19	.06	50	25	17	.0	256	36	2.0	7.5	267
Dec. 1	Dec. 10	168	87	.5	21	.40	53	25	15	.0	270	37	3.0	8.0	274
Dec. 11	Dec. 20	80	54	.7	13	.20	55	17	16	.0	263	37	5.0	5.5	278
Dec. 21	Dec. 31	20	36	1.8	30	2.8	55	29	27	.0	301	51	7.0	6.5	319
Jan. 1	Jan. 10	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Jan. 11	Jan. 19	80	67	.8	22	.20	47	21	18	.0	257	32	0.10	8.7	296
Jan. 21	Jan. 31	280	62	.2	16	.50	32	14	13	.0	137	28	5.0	6.2	193
Feb. 1	Feb. 9	20	40	2.0	20	.15	47	23	17	.0	238	40	0.10	7.5	273
Feb. 10	Feb. 18	10.0	11	1.1	14	.20	54	26	16	.0	257	46	11	8.5	293
Feb. 19	Feb. 28	30	24	.8	16	.09	58	26	16	.0	274	40	6.5	8.5	305
Mar. 1	Mar. 10	50	46	.9	12	.17	44	21	14	.0	213	35	3.0	5.0	243
Mar. 11	Mar. 20	10.0	11	1.1	12	.15	56	18	11	.0	264	43	10	7.0	275
Mar. 21	Mar. 31	10.0	11	1.1	13	.11	58	24	14	.0	247	49	4.0	3.8	279
Apr. 1	Apr. 10	8.0	10.0	1.2	18	.19	58	25	12	.0	267	36	2.3	4.5	288
Apr. 11	Apr. 20	5.0	3.6	.7	13	.23	56	26	13	.0	266	46	1.4	5.0	296
Apr. 21	Apr. 30	14	11	.8	11	.19	58	34	9.3	.0	271	44	3.4	5.5	289
May 1	May 10	25	22	.9	13	.12	53	20	12	.0	257	47	4.4	5.0	299
May 11	May 20	12	11	.9	14	.15	54	22	18	.0	268	43	5.0	6.3	289
May 21	May 31	5.0	6.0	1.2	12	.13	58	26	16	.0	.....	43	2.8	4.3	292
June 1	June 10	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
June 11	June 20	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
June 21	June 30	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
July 1	July 10	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
July 11	July 20	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
July 21	July 31	20	22	1.1	19	.28	64	25	13	.0	270	38	1.0	5.0	276
Mean		74	39	.8	16	.32	52	24	16	.0	247	37	3.4	7.5	276
Per ct. of anhydrous residue		.....	.....	.....	5.8	[a].2	18.7	8.6	5.8	43.7	.....	13.3	1.2	2.7	....

[a] Fe_2O.

TABLE 31.—*Mineral analyses of water from Sangamon River near Chandlerville, Ill.*

[Parts per million unless otherwise stated.]

Date (1906–7)		Turbidity.	Suspended matter.	Coefficient of fineness.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.	Mean gage height (feet).
From—	To—															
Aug. 1	Aug. 10	125	81	0.6	18	0.20	54	26	23	0.0	290	25	1.7	8.8	293	3.7
Aug. 11	Aug. 20	115	187	.6	17	.50	39	22	11	.0	182	26	3.4	5.5	231	4.6
Aug. 21	Aug. 30	330	170	.5	15	.07	43	19	18	.0	193	31	4.0	5.0	232	4.2
Aug. 31	Sept. 9	300	163	.5	18	.09	50	24	7.4	.0	236	26	2.7	6.5	247	3.6
Sept. 10	Sept. 19	160	116	.7	20	.18	53	33	13	.0	320	32	2.0	7.0	317	2.7
Sept. 20	Sept. 23	140	105	.8	17	.06	51	27	16	.0	325	28	2.1	12	318	2.3
Sept. 30	Oct. 9	110	92	.8	14	.04	56	33	20	.0	287	30	1.7	9.5	287	2.7
Oct. 10	Oct. 13	50	52	1.0	14	.04	56	32	31	.0	295	33	1.5	13	295	2.7
Oct. 24	Oct. 29									.0						2.3
Nov. 1	Nov. 8	20	11	.6	12	.03	66	33	20	.0	363	39	1.0	11	340	2.7
Nov. 9	Nov. 18	40	32	.8	7.2	.01	64	32	16	.0	345	32	0.5	12	310	1.9
Nov. 20	Nov. 30									.0						3.2
Dec. 1	Dec. 10	270	164	.6	20	.10	49	24	27	.0	260	42	6.0	12	266	4.4
Dec. 11	Dec. 20	160	94	.6	16	.22	55	27	13	.0	252	37	4.0	7.0	294	10.5
Dec. 21	Dec. 31	113	149	1.3	13	.72	58	28	14	.0	283	41	4.0	9.0	296	9.3
Jan. 1	Jan. 10	155	83	.5	24	.49	55	32	18	.0	306	38	8.0	7.5	318	10.7
Jan. 11	Jan. 20	90	73	.8	22	.40	51	23	15	.0	260	44	6.0	6.5	309	11.5
Jan. 21	Jan. 31	225	99	.4	23	2.6	25	7.6	7.9	.0	105	24	5.0	5.5	184	15.5
Feb. 1	Feb. 9	50	9.0	.2	15	.36	52	25	16	.0	234	36	5.5	6.0	272	12.8
Feb. 11	Feb. 18	45	22	.5	17	.19	53	24	14	.0	252	42	6.5	8.2	279	10.5
Feb. 19	Feb. 28	20	17	.8	9.8	.15	52	24	14	.0	247	38	6.0	6.7	283	9.9
Mar. 1	Mar. 10	30	28	.9	10	.16	57	25	8.8	.0	237	51	5.0	8.0	266	8.5
Mar. 11	Mar. 20															6.5
Mar. 21	Mar. 31	180	120	.7	16	.50	50	24	10.0	.0	239	40	6.0	8.5	274	11.6
Apr. 1	Apr. 10	130	95	.7	14	.22	49	23	11	.0	237	43	20	7.0	265	10.4
Apr. 11	Apr. 20	60	39	.6	16	.11	45	22	11	.0	274	40	6.8	7.0	309	8.4
Apr. 21	Apr. 30	80	60	.8	10	.61	55	30	13	.0	245	43	9.2	7.5	294	7.3
May 1	May 10	120	80	.7	12	.11	53	27	10.0	.0	242	40	10	8.3	279	9.3
May 11	May 20	124	100	.8	10	.23	56	27	12	.0	252	40	10	7.3	316	9.0
May 21	May 31	200	180	.9	11	.80	53	27	16	.0	230	43	13	6.3	295	9.3
June 1	June 10	204	114	.6	18	.16	49	26	16	.0	235	34	9.2	6.0	302	10.1
June 11	June 20	170	106	.6	14	.30	57	24	12	.0	234	35	9.0	5.0	298	11.0
June 21	June 30	350	215	.6	16	.15	62	20	20	.0	265	36	6.2	6.5	286	8.9
July 1	July 10	10	4.2	.4	16	.21	63	25	15	.0	270	28	16	6.0	293	7.3
July 11	July 20	450	333	.7	14	.09	60	20	10.0	.0	229	28	6.2	5.0	259	10.4
July 21	July 31	248	164	.7	18	.38	43	17	11	.0	182	27	3.8	4.5	213	11.1
Mean		154	102	.7	15	.32	52	25	15	.0	255	36	6.1	7.6	282	....
Per ct. of anhydrous residue		.....	.....	.....	5.3	a .2	18.4	8.8	5.3	44.4	.....	12.7	2.2	2.7	.....	....

a Fe_2O_3.

TABLE 32.—*Mineral analyses of water from Illinois River near Lasalle, Ill.*

[Parts per million unless otherwise stated.]

Date (1906–7).		Turbidity.	Suspended matter.	Coefficient of fineness.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.
From—	To—														
Aug. 1	Aug. 10	70	36	0.5	14	0.50	33	18	22	0.0	174	41	7.0	28	265
Aug. 11	Aug. 20	50	25	.5	19	.10	39	18	17	.0	170	28	6.0	20	262
Aug. 21	Aug. 30	235	113	.5	25	.05	38	19	20	.0	172	34	1.0	18	252
Aug. 31	Sept. 9	50	33	.7	10	.03	39	24	8.0	.0	169	30	3.0	17	235
Sept. 10	Sept. 19	50	32	.6	8.4	.30	39	18	15	.0	171	32	5.0	18	221
Sept. 20	Sept. 29	110	71	.6	6.8	.07	42	17	12	.0	175	39	7.0	21	241
Sept. 30	Oct. 9	290	162	.6	13	.20	50	.....	18	.0	180	49	7.0	19	284
Oct. 10	Oct. 19	60	30	.5	6.8	.09	45	23	18	.0	200	43	3.5	7.5	260
Oct. 20	Oct. 28	40	35	.9	9.8	.04	51	22	21	.0	220	45	4.0	19	268
Oct. 30	Nov. 8	40	25	.6	7.8	.02	51	23	24	.0	240	53	6.0	16	275
Nov. 9	Nov. 19	30	20	.7	10	.12	63	29	25	.0	224	64	4.0	18	276
Nov. 20	Nov. 30	100	75	.8	10	.06	57	26	17	.0	210	66	6.0	13	300
Dec. 1	Dec. 10	120	83	.7	13	.12	54	27	15	.0	219	72	7.0	14	320
Dec. 11	Dec. 20	128	72	.6	13	.32	51	24	16	.0	195	62	6.0	11	284
Dec. 21	Dec. 31	174	166	1.0	10	.12	53	26	17	.0	210	64	7.0	12	311
Jan. 1	Jan. 10	206	155	.8	15	.10	52	23	17	.0	220	68	9.0	9.7	296
Jan. 11	Jan. 20	248	250	1.0	18	.36	51	21	11	.0	206	56	8.0	9.2	298
Jan. 21	Jan. 31	.....	.....	.....	.....	.....	.....	.....	.....	.0	.....	.....	.....	.....	.....
Feb. 1	Feb. 9	15	15	1.0	5.6	.28	52	20	13	.0	200	53	8.0	11	289
Feb. 10	Feb. 18	10	11	1.1	11	.08	53	22	17	.0	214	51	6.5	16	311
Feb. 19	Feb. 28	30	22	.7	8.0	.13	48	20	14	.0	195	50	7.0	13	273
Mar. 1	Mar. 10	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Mar. 11	Mar. 20	100	92	.9	13	.22	51	20	19	.0	198	55	3.2	10.0	257
Mar. 21	Mar. 31	150	144	1.0	12	.26	46	19	12	.0	205	57	10.	9.0	272
Apr. 1	Apr. 10	105	168	1.6	18	.38	50	20	13	.0	205	73	6.8	7.0	299
Apr. 11	Apr. 20	40	28	.7	12	.15	56	27	16	.0	215	78	7.0	6.5	344
Apr. 21	Apr. 30	35	30	.8	9.4	.20	54	27	10	.0	207	52	4.6	10	266
May 1	May 10	100	63	.6	11	.31	50	18	12	.0	208	52	12	9.8	272
May 11	May 20	48	48	1.0	6.0	.80	52	19	18	.0	185	48	14	14	300
May 21	May 31	230	225	1.0	8.0	.27	54	22	9.5	.0	208	49	9.6	8.5	279
June 1	June 10	95	70	.7	13	.38	51	19	10.0	.0	213	38	14	8.3	307
June 11	June 20	280	340	1.2	9.6	.38	59	22	12	.0	227	31	0.3	3.0	276
June 21	June 30	161	110	.7	16	.50	60	24	14	.0	233	37	3.6	10	276
July 1	July 10	1,610	1,556	1.0	18	.15	53	18	11	.0	197	47	6.0	10	256
July 11	July 20	270	203	.8	15	.18	53	19	13	.0	206	36	7.0	9.0	255
July 21	July 31	130	103	.8	15	.13	57	21	15	.0	228	34	7.0	12	288
Mean		159	136	.8	12	.21	50	22	16	.0	203	50	6.6	13	278
Per ct. of anhydrous residue		.....	.....	.....	4.5	[b].1	18.6	8.1	5.9	37.0	.....	18.6	2.4	4.8	....

[a] Fe_2O_3.

TABLE 33.—*Mineral analyses of water from Illinois River near Peoria, Ill.*

[Parts per million unless otherwise stated.]

Date (1906–7).		Turbidity.	Suspended matter.	Coefficient of fineness.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.
From—	To—														
Aug. 1	Aug. 9	50	25	0.5	13	0.10	40	20	28	0.0	182	21	10.0	27	266
Aug. 31	Sept. 9	60	29	.5	12	.20	42	20	15	.0	166	28	4.0	20	245
Sept. 10	Sept. 19	30	36	1.2	20	.14	45	18	23	.0	187	29	4.0	19	260
Sept. 20	Sept. 29	40	21	.5	6.4	.10	42	18	15	.0	177	24	5.0	20	222
Sept. 30	Oct. 9	40	26	.6	8.4	.03	44	18	22	.0	174	40	6.0	22	249
Oct. 10	Oct. 19	40	20	.5	9.8	.04	46	23	22	.0	196	46	7.0	20	279
Oct. 20	Oct. 29	30	20	.7	8.8	.02	43	19	21	.0	190	35	4.0	18	233
Oct. 30	Nov. 8	20	9.4	.5	14	.06	46	20	18	.0	216	40	5.5	20	264
Nov. 9	Nov. 19	10.0	11	1.1	6.4	.03	48	22	18	.0	195	41	7.0	21	250
Nov. 20	Nov. 30	20	17	.8	8.8	.08	49	22	18	.0	185	52	7.0	18	259
Dec. 1	Dec. 10	20	16	.8	10	.11	51	24	14	.0	213	64	8.0	15	310
Dec. 11	Dec. 20	40	41	1.0	11	.28	54	24	20	.0	198	62	10	13	293
Dec. 21	Dec. 31	15	13	.9	17	.14	52	24	20	.0	229	59	12	12	294
Jan. 1	Jan. 10	30	22	.7	20	.20	52	23	21	.0	239	59	6.0	12	310
Jan. 11	Jan. 20	80	40	.5	21	.64	50	22	14	.0	207	69	7.5	8.7	309
Jan. 21	Jan. 31	235	73	.3	12	.....	41	17	18	.0	139	50	7.0	7.5	223
Feb. 1	Feb. 9	149	63	.4	14	1.3	40	16	14	.0	148	50	11	8.0	242
Feb. 10	Feb. 18	12	7.6	.6	11	.49	49	20	13	.0	185	65	11	11	275
Mar. 1	Mar. 10	20	10.0	.5	10	.11	49	21	19	.0	180	60	7.1	9.8	279
Mar. 11	Mar. 20	45	36	.8	14	.22	52	20	18	.0	204	59	12	11	275
Mar. 21	Mar. 31	45	22	.5	6.6	.25	52	24	14	.0	198	57	10	9.5	272
Apr. 1	Apr. 10	35	26	.7	13	.26	50	22	19	.0	195	59	12	8.8	272
Apr. 11	Apr. 20	35	20	.6	13	.15	50	18	15	.0	207	54	15	7.5	304
Apr. 21	Apr. 30	33	26	.8	10	.14	53	24	13	.0	210	55	11	12	271
May 1	May 10	15	13	.9	7.4	.16	51	18	12	.0	233	53	8.0	9.8	276
May 11	May 20	20	21	1.0	10	.28	51	22	12	.0	205	60	8.8	9.5	289
May 21	May 31	20	22	1.0	14	.28	52	24	9.8	.0	218	50	9.2	10.0	283
June 1	June 10	44	25	.6	8.6	.12	52	22	15	.0	224	43	3.2	8.5	277
June 11	June 20	30	19	.6	8.0	.32	61	24	16	.0	.....	37	3.0	11	290
June 21	June 30	60	31	.5	8.8	.16	58	20	15	.0	217	42	8.0	10	272
July 1	July 10	30	26	.9	11	.12	56	23	15	.0	229	39	3.5	12	270
July 11	July 20	60	50	.8	13	.18	52	16	8.7	.0	195	34	7.2	10	257
July 21	July 31	23	19	.8	14	.15	55	20	14	.0	209	37	6.5	8.5	257
Feb. 19	Feb. 27	25	.....	.....	11	.07	50	20	18	.0	195	57	7.0	13	275
Mean		43	26	.8	12	.21	49	21	17	.0	198	48	7.8	13	271
Per ct. of anhydrous residue		.....	.....	.....	4.5	[a].1	18.5	7.9	6.4	36.7	.....	18.1	2.9	4.9	....

[a] Fe_2O_3.

TABLE 34.—*Mineral analyses of water from Illinois River near Kampsville, Ill.*

[Parts per million unless otherwise stated.]

Date (1906–7). From—	To—	Turbidity.	Suspended matter.	Coefficient of fineness.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.	Mean gage height (feet).
Aug. 1	Aug. 10	105	72	0.7	11	0.20	46	21	34	0.0	208	31	5.0	24	278	14.8
Aug. 11	Aug. 20	218	113	.5	12	.30	39	19	20	.0	185	30	5.4	22	262	15.0
Aug. 21	Aug. 30	230	120	.5	11	.05	44	17	20	.0	177	33	5.0	20	249	15.0
Aug. 31	Sept. 9	147	89	.6	8.2	.06	40	18	17	.0	172	34	4.0	20	236	15.1
Sept. 11	Sept. 19	135	98	.7	7.2	.15	41	20	15	.0	181	29	4.2	18	228	15.2
Sept. 20	Sept. 29	135	121	.9	8.0	.10	44	16	17	.0	187	30	7.0	20	244	14.9
Sept. 30	Oct. 9	218	184	.8	17	.10	41	16	18	.0	170	29	6.0	17	233	15.2
Oct. 10	Oct. 19	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	15.0
Oct. 20	Oct. 28	80	58	.7	9.2	.08	49	24	42	.0	226	47	3.0	62	341	15.0
Oct. 30	Nov. 8	50	24	.5	14	.03	47	20	21	.0	221	39	4.0	19	269	14.8
Nov. 10	Nov. 19	80	70	.9	6.8	.03	50	24	22	.0	220	39	4.0	21	274	14.8
Nov. 20	Nov. 30	170	84	.5	17	.32	45	20	16	.0	196	44	6.0	12	246	15.2
Dec. 1	Dec. 10	290	127	.4	19	.65	46	21	17	.0	206	52	3.0	10	269	15.7
Dec. 11	Dec. 20	40	35	.9	13	.17	54	22	13	.0	226	64	4.0	13	311	15.8
Dec. 21	Dec. 31	40	51	1.3	19	.36	58	30	18	.0	265	70	3.0	11	323	15.6
Jan. 1	Jan. 8	290	200	.7	25	.49	51	22	21	.0	235	60	3.0	9.5	298	15.7
Jan. 11	Jan. 20	400	260	.6	16	.64	34	15	11	.0	158	53	3.5	4.7	227	17.2
Jan. 21	Jan. 31	310	220	.7	15	.28	33	15	17	.0	150	42	4.0	6.5	215	22.9
Feb. 1	Feb. 9	200	133	.7	11	.45	34	18	15	.0	153	44	7.0	5.7	221	22.0
Feb. 10	Feb. 18	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	19.8
Feb. 19	Feb. 26	230	129	.6	9.6	.24	27	9.1	44	.0	126	38	.4	34	.....	19.2
Mar. 1	Mar. 10	60	50	.8	14	1.0	24	10.0	18	.0	114	30	.4	4.8	160	17.9
Mar. 11	Mar. 20	70	62	.9	12	.25	52	20	16	.0	220	34	3.0	10	269	16.5
Mar. 21	Mar. 31	210	105	.5	12	.46	47	17	21	.0	210	41	3.0	12	266	16.1
Apr. 1	Apr. 10	280	192	.7	11	.53	53	23	15	.0	223	38	6.0	9.0	280	17.8
Apr. 11	Apr. 20	60	46	.8	7.4	.12	54	22	12	.0	235	48	6.0	6.5	278	20.2
Apr. 21	Apr. 30	90	62	.7	4.4	.11	56	28	18	.0	237	52	1.3	9.5	299	21.3
May 1	May 10	330	295	.9	13	.16	50	22	15	.0	208	47	4.6	10	280	18.9
May 11	May 20	130	131	1.0	7.0	.57	49	24	18	.0	219	49	4.0	18	306	16.5
May 21	May 31	150	143	1.0	8.8	.12	56	24	13	.0	218	54	4.8	8.3	280	15.8
June 1	June 10	340	373	1.1	10	.26	51	25	13	.0	223	44	4.0	7.3	271	16.6
June 11	June 20	495	520	1.1	12	.26	58	25	17	.0	.....	35	2.5	11	293	17.6
June 21	June 30	166	165	1.0	13	.32	68	23	9.4	.0	244	47	10	13	310	16.1
July 1	July 10	325	324	1.0	12	.12	55	21	16	.0	239	34	8.0	10	281	15.0
July 11	July 20	238	196	.8	18	.25	50	19	13	.0	202	31	6.0	10	260	16.5
July 21	July 31	74	64	.9	15	.34	54	20	11	.0	219	27	1.2	8.0	242	19.7
Mean		188	145	.8	12	.27	47	20	18	.0	202	42	4.3	15	267	.....
Per ct. of anhydrous residue		.....	.....	.....	4.6	[a] .1	18.2	7.8	7.0	38.5	.....	16.3	1.7	5.8	.....	.....

[a] Fe_2O_3.

TABLE 35.—*Mineral analyses of water from Kaskaskia River near Shelbyville, Ill.*

[Parts per million unless otherwise stated.]

Date (1906–7).		Turbidity.	Suspended matter.	Coefficient of fineness.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.	Mean gage height (feet).
From—	To—															
Aug. 1	Aug. 10	40	25	0.6	9.2	0.10	44	23	15	0.0	245	30	0.5	6.2	256	1.8
Aug. 11	Aug. 20	270	149	.6	13	.30	38	23	15	.0	233	28	2.1	6.5	243	2.2
Aug. 21	Aug. 30	204	81	.4	16	.60	47	24	15	.0	217	22	3.5	5.0	236	2.4
Aug. 31	Sept. 9	50	34	.7	20	.11	55	30	3.0	.0	274	30	2.0	5.0	279	1.7
Sept. 10	Sept. 19	50	41	.8	9.6	.30	38	23	17	.0	.....	25	1.2	10.0	218	1.4
Sept. 20	Sept. 29	40	28	.7	9.0	.06	50	29	24	.0	289	26	3.5	7.5	286	1.4
Sept. 30	Oct. 9	121	63	.5	33	.13	45	25	17	.0	220	38	.6	6.0	285	1.8
Oct. 10	Oct. 19	30	31	1.0	6.4	.06	42	32	18	.0	241	31	1.2	6.5	252	1.7
Oct. 20	Oct. 29	20	19	1.0	14	.02	57	28	19	.0	330	36	.2	9.0	301	1.4
Oct. 30	Nov. 6	20	13	.6	13	.03	64	38	23	.0	355	37	.3	9.5	340	1.3
Nov. 10	Nov. 19	30	15	.5	8.8	.10	63	36	14	.0	345	33	.6	10.0	334	1.6
Nov. 20	Nov. 30	195	84	.4	23	.04	52	29	15	.0	275	31	3.0	5.3	273	6.5
Dec. 1	Dec. 10	100	102	1.0	17	.24	54	25	13	.0	267	38	7.0	5.5	268	7.7
Dec. 11	Dec. 20	40	45	1.1	18	.24	56	26	14	.0	267	33	8.0	6.7	285	7.1
Dec. 21	Dec. 31	30	43	1.4	12	.24	53	26	15	.0	293	42	10	5.5	296	6.1
Jan. 1	Jan. 10	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	6.5
Jan. 11	Jan. 20	194	100	.5	25	1.0	42	19	10	.0	207	42	5.5	4.0	258	13.2
Jan. 22	Jan. 31	220	101	.5	14	.36	34	16	11	.0	153	31	5.0	5.0	192	12.0
Feb. 1	Feb. 9	20	27	1.4	16	.....	58	28	15	.0	271	37	10	4.2	298	5.4
Feb. 10	Feb. 18	25	29	1.2	13	.13	57	26	12	.0	280	40	9.0	7.0	304	4.5
Feb. 19	Feb. 28	25	26	1.0	14	.09	57	26	15	.0	280	37	12	5.2	297	4.4
Mar. 1	Mar. 10	100	94	.9	17	.19	52	27	19	.0	237	38	13	4.8	292	5.2
Mar. 11	Mar. 20	260	77	.4	19	.78	45	19	12	.0	196	46	12	6.5	267	9.6
Mar. 21	Mar. 31	50	31	.6	17	.17	55	25	13	.0	260	40	22	4.3	281	5.8
Apr. 1	Apr. 10	10	18	1.8	16	.19	56	25	10	.0	270	40	12	4.0	282	4.4
Apr. 11	Apr. 20	8	13	1.6	17	.15	49	19	9.5	.0	257	40	9.0	3.5	282	3.7
Apr. 21	Apr. 30	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	3.7
May 1	May 10	30	27	.9	16	.12	54	20	8.4	.0	257	35	12	3.8	290	4.0
May 11	May 20	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	4.1
May 21	May 31	275	270	1.0	14	.21	57	28	13	.0	276	39	15	3.8	303	4.2
June 1	June 10	80	84	1.5	14	.34	51	23	9.6	.0	225	28	12	2.8	264	7.1
June 11	June 20	85	79	.9	16	.23	67	28	8.9	.0	.....	34	1.1	2.8	313	5.3
June 21	June 30	303	377	1.2	15	.21	66	28	7.9	.0	280	29	8.0	3.8	272	4.7
July 1	July 10	40	38	1.0	15	.14	70	29	9.5	.0	304	34	2.0	6.0	315	3.2
July 11	July 20	415	392	.9	18	.30	59	25	10	.0	258	30	16	.....	274	4.4
July 21	July 31	255	208	.8	19	.27	65	27	14	.0	268	28	8.0	4.5	284	5.4
Mean		110	84	.9	16	.23	53	26	13	.0	262	34	6.9	5.6	279	....
Per ct. of anhydrous residue		.....	.....	.....	5.6	*a* .1	18.7	9.2	4.6	45.4	.....	12.0	2.4	2.0	.....	....

a Fe_2O_3.

TABLE 36.—*Mineral analyses of water from Kaskaskia River near Carlyle, Ill.*

[Parts per million unless otherwise stated.]

Date (1906–7).		Turbidity.	Suspended matter.	Coefficient of fineness.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.	Mean gage height (feet).
From—	To—															
Aug. 1	Aug. 10	120	70	0.6	16	0.20	42	24	15	0.0	271	19	2.0	9.0	273	....
Aug. 11	Aug. 20	224	126	.6	11	.10	44	24	16	.0	218	24	1.9	7.5	235	....
Aug. 22	Aug. 30	300	227	.8	20	.06	36	17	16	.0	.....	.....	.....	.....	204	....
Aug. 31	Sept. 8	262	168	.6	21	.07	43	20	7.1	.0	198	23	1.7	5.5	225	....
Sept. 10	Sept. 19	127	71	.6	61	.15	42	22	22	.0	221	25	0.5	6.0	284	....
Sept. 20	Sept. 29	106	55	.5	16	.07	46	20	14	.0	251	26	1.2	9.5	274	....
Sept. 30	Oct. 9	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Oct. 10	Oct. 19	70	46	.7	13	.08	44	18	17	.0	204	32	0.9	12	233	....
Oct. 21	Oct. 28	40	29	.7	14	.8	55	25	24	.0	284	29	0.5	7.5	273	....
Oct. 30	Nov. 8	20	12	.6	17	.03	53	26	15	.0	270	29	0.6	8.5	268	2.3
Nov. 10	Nov. 19	20	13	.6	8.8	.03	56	25	20	.0	294	28	0.5	11	269	2.3
Nov. 20	Nov. 30	273	113	.4	22	.18	21	16	13	.0	154	24	3.0	5.0	198	4.8
Dec. 1	Dec. 10	293	178	.6	18	.28	37	16	17	.0	205	38	5.5	11	225	14.1
Dec. 11	Dec. 20	184	133	.7	17	.64	43	23	16	.0	192	28	5.0	6.0	251	14.7
Dec. 21	Dec. 31	30	36	1.2	14	.20	56	28	16	.0	272	45	4.0	7.5	291	9.0
Jan. 1	Jan. 10	270	108	.4	28	2.5	24	11	15	.....	116	40	5.0	5.0	200	19.1
Jan. 11	Jan. 19	133	34	.2	23	1.0	31	11	14	.0	148	40	5.0	4.7	213	20.0
Jan. 21	Jan. 31	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	21.2
Feb. 1	Feb. 9	40	51	1.3	17	.32	39	18	13	.0	175	33	6.0	6.0	214	17.5
Feb. 10	Feb. 18	50	42	.8	13	.20	51	21	14	.0	224	41	6.0	6.5	262	8.5
Feb. 19	Feb. 28	37	26	.7	16	.08	55	23	18	.0	260	46	7.0	7.0	301	7.5
Mar. 1	Mar. 10	110	104	.9	13	.34	47	21	14	.0	203	52	6.0	5.8	277	9.2
Mar. 11	Mar. 20	350	186	.5	24	1.1	28	8.9	6.0	.0	119	28	3.0	7.0	189	17.4
Mar. 21	Mar. 31	140	91	.6	15	.15	40	19	11	.....	180	38	10	6.5	239	14.0
Apr. 1	Apr. 10	90	69	.8	10.0	.15	54	26	12	.....	210	48	8.0	7.3	281	7.2
Apr. 11	Apr. 20	10.0	15	1.5	11	1.1	57	24	16	.....	274	46	6.0	7.0	292	5.9
Apr. 21	Apr. 30	175	182	1.0	12	.19	49	26	14	.....	217	44	3.6	8.3	268	5.8
May 1	May 10	180	117	.6	21	.66	42	18	11	.0	178	40	6.0	6.0	239	11.2
May 11	May 20	205	176	.9	12	.42	44	22	14	.0	213	46	14	7.5	249	10.4
May 21	May 31	600	305	.5	15	.15	45	20	13	.0	208	35	7.0	6.8	242	....
June 1	June 10	380	315	.8	15	.47	29	12	11	.0	116	31	3.8	4.8	166	16.8
June 11	June 20	235	206	.9	15	.53	46	18	11	.0	198	19	7.0	3.8	225	14.1
June 21	June 30	285	234	.8	16	.28	57	21	11	.0	255	32	6.0	5.3	271	8.4
July 1	July 10	150	145	1.0	17	.16	61	24	10.0	.0	265	27	8.0	6.0	298	5.3
July 11	July 20	210	183	.9	16	.16	52	24	12	.0	245	30	5.0	7.0	255	4.2
July 21	July 31	550	426	.8	17	.36	44	16	11	.0	194	30	8.0	5.0	239	9.8
Mean		184	126	.7	17	.39	47	20	14	.0	213	34	4.8	6.9	248	....
Per ct. of anhydrous residue		.....	.....	.....	6.8	[a].2	18.9	8.0	5.6	42.1	.....	13.7	1.9	2.8	.....	.....

[a] Fe_2O_3.

TABLE 37.—*Mineral analyses of water from Muddy River near Murphysboro, Ill.*

[Parts per million unless otherwise stated.]

Date (1906–7). From—	To—	Turbidity.	Suspended matter.	Coefficient of fineness.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.	Mean gage height (feet).
Aug. 1	Aug. 10	158	71	0.4	17	0.10	33	17	24	0.0	101	68	1.0	20	258	....
Aug. 11	Aug. 20	730	241	.3	28	1.6	15	15	22	.0	75	49	2.1	19	189	....
Aug. 21	Aug. 29	550	177	.3	27	5.0	17	8.4	13	.0	54	41	1.0	11	158	....
Aug. 31	Sept. 9	224	104	.5	11	1.7	24	11	9.5	.0	67	64	1.7	21	213	....
Sept. 10	Sept. 19	445	249	.6	17	2.5	18	8.7	13	.0	43	41	2.0	11	150	....
Sept. 20	Sept. 29	248	136	.5	15	0.30	21	11	14	.0	63	48	1.5	15	166	....
Sept. 30	Oct. 9	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Oct. 12	Oct. 17	123	64	.5	14	0.7	39	18	25	.0	154	74	3.5	16	274	....
Oct. 20	Oct. 29	80	42	.5	23	1.0	30	13	27	.0	88	89	1.0	15	247	....
Oct. 31	Nov. 8	40	24	.6	21	0.08	34	16	32	.0	108	107	1.0	14	285	....
Nov. 10	Nov. 19	190	74	.4	13	0.15	38	17	27	.0	90	112	.4	17	278	2.9
Nov. 20	Nov. 30	728	612	.8	16	1.3	12	6.3	12	.0	31	28	1.5	6.3	115	15.7
Dec. 1	Dec. 10	385	115	.3	44	5.0	17	8.1	21	.0	54	65	2.5	13	217	6.6
Dec. 11	Dec. 20	408	180	.4	45	4.0	18	4.4	17	.0	36	50	4.0	6.8	219	11.7
Dec. 21	Dec. 31	290	26	.9	33	4.5	16	10	20	.0	54	70	2.0	8.7	204	10.4
Jan. 1	Jan. 10	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	23.3
Jan. 11	Jan. 20	200	49	.2	44	4.1	9.6	4.1	16	.0	45	42	3.0	5.5	183	24.4
Jan. 21	Jan. 31	240	70	.3	32	4.5	17	5.2	15	.0	35	46	3.0	5.5	146	19.2
Feb. 2	Feb. 9	185	123	.7	29	3.0	19	8.7	23	.0	53	72	5.0	8.2	218	8.2
Feb. 11	Feb. 18	40	19	.5	24	1.5	30	15	29	.0	88	106	3.5	17	294	1.8
Feb. 19	Feb. 28	100	66	.7	16	0.55	33	18	30	.0	89	137	1.7	23	342	3.1
Mar. 1	Mar. 10	290	154	.4	37	4.9	21	12	25	.0	46	93	3.2	11	252	6.2
Mar. 11	Mar. 20	340	276	.6	32	4.9	17	6.1	16	.0	49	51	1.7	6.5	193	12.4
Mar. 21	Mar. 31	170	59	.3	16	5.3	28	12	17	.0	79	72	1.6	10	230	7.5
Apr. 1	Apr. 10	100	44	.4	19	1.11	43	22	34	.0	144	120	3.2	19	339	1.8
Apr. 11	Apr. 20	35	18	.5	16	0.21	51	21	35	.0	46	186	1.2	25	424	2.3
Apr. 21	Apr. 30	80	34	.4	15	0.8	46	26	31	.0	104	138	1.1	21	343	4.2
May 1	May 10	340	222	.6	17	2.5	24	6.9	18	.0	79	81	1.8	12	229	5.6
May 11	May 20	190	156	.8	18	2.20	18	9.3	20	.0	57	61	1.8	8.3	193	7.1
May 21	May 31	150	124	.8	26	0.7	29	12	19	.0	72	62	1.0	10	210	2.8
June 1	June 10	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	9.3
June 11	June 20	230	160	.7	19	1.4	14	7.4	11	.0	32	24	5.0	7.0	122	18.5
June 21	June 30	435	373	.8	20	0.83	20	10	12	.0	66	38	1.5	8.0	139	9.6
July 1	July 10	65	31	.5	22	1.3	24	5.8	14	.0	78	42	.6	9.0	178	5.3
July 11	July 20	80	57	.7	17	0.15	31	12	16	.0	97	59	1.1	13	206	4.3
July 21	July 31	210	105	.5	39	2.8	22	7.9	20	.0	90	45	.8	11	212	9.6
Mean		245	129	.5	24	2.1	25	12	20	.0	72	72	2.0	13	225	....
Per ct. of anhydrous residue		.....	.....	.....	11.5	[a]1.5	12.2	5.6	9.9	17.1	.....	35.0	1.0	6.2	.....	.....

[a] Fe_2O_3.

TABLE 38.—*Mineral analyses of water from Mississippi River near Moline, Ill.*

[Parts per million unless otherwise stated.]

Date (1906–7).		Turbidity.	Suspended matter.	Coefficient of fineness.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.	Mean gage height (feet).
From—	To—															
Feb. 1	Feb. 9	15	14	0.9	29	0.32	36	19	13	0.0	203	25	1.7	4.5	241	4.4
Feb. 10	Feb. 18	20	21	1.0	19	.56	41	18	7.6	.0	205	29	1.7	4.5	219	3.2
Feb. 19	Feb. 28	70	44	.6	11	.20	33	13	11	.0	158	21	2.3	7.0	188	4.8
Mar. 1	Mar. 10	65	59	.9	15	.....	30	13	15	.0	144	19	3.2	4.0	168	5.3
Mar. 11	Mar. 20	60	50	.8	18	.38	32	12	11	.0	168	15	3.0	3.8	185	5.3
Mar. 21	Mar. 31	150	116	.8	18	.39	32	8.4	18	.0	151	23	4.0	4.0	168	6.6
Apr. 1	Apr. 10	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	9.9
Apr. 11	Apr. 20	55	52	.9	11	.24	20	10.0	11	.0	91	24	2.2	3.5	124	12.8
Apr. 21	Apr. 30	25	25	1.0	8.0	.23	24	11	7.1	.0	118	17	1.7	2.5	128	10.3
May 1	May 10	20	14	.7	18	.24	26	8.2	8.7	.0	123	21	1.0	2.5	152	7.8
May 11	May 20	55	54	1.0	12	.8	27	9.8	11	.0	131	24	0.4	8.3	156	6.5
May 21	May 31	100	97	1.0	10	.50	27	12	5.9	.0	116	21	1.1	2.0	149	6.8
June 1	June 10	90	70	.8	12	.34	31	13	11	.0	.....	17	2.0	1.8	172	7.1
June 11	June 20	145	142	.9	16	.31	37	16	7.7	.0	155	20	0.4	2.5	189	7.4
June 21	June 30	210	280	1.3	14	.65	42	15	6.8	.0	161	27	1.7	3.0	186	6.6
July 1	July 10	185	185	1.0	13	.31	40	14	8.1	.0	166	31	0.3	2.5	203	6.8
July 11	July 20	372	287	.8	19	.42	41	15	8.6	.0	173	35	1.8	2.0	212	8.3
July 21	July 31	350	295	.8	22	.32	41	16	10.0	.0	171	34	2.7	4.5	208	7.7
Mean.....		117	106	.9	16	0.39	33	13	10	.0	152	24	1.8	3.7	179	....
Per ct. of anhydrous residue..		.....	.....	.....	9.0	[a]0.3	18.7	7.3	5.7	42.3	.....	13.6	1.0	2.1	.....	....

[a] Fe_2O_3.

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TABLE 39.—*Mineral analyses of water from Mississippi River near Quincy, Ill.*

[Parts per million unless otherwise stated.]

Date (1906–7).		Turbidity.	Suspended matter.	Coefficient of fineness.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.	Mean gage height (feet).
From—	To—															
Aug. 1	Aug. 10	150	104	0.7	17	0.10	38	17	16	0.0	180	25	1.0	5.5	224	5.4
Aug. 11	Aug. 20	540	287	.5	23	.20	34	14	16	.0	161	23	2.1	5.0	192	6.4
Aug. 21	Aug. 30	360	190	.5	21	2.0	36	17	18	.0	166	23	2.0	5.5	197	5.7
Aug. 31	Sept. 9															5.6
Sept. 10	Sept. 18	245	168	.7	17	.5	31	13	10	.0	168	24	2.8	3.5	187	6.0
Sept. 20	Sept. 29	224	149	.7	16	.40	35	18	11	.0	156	20	1.8	9.0	196	5.9
Sept. 30	Oct. 9	263	169	.6	17	.12	38	21	12	.0	162	22	2.0	4.5	200	6.0
Oct. 10	Oct. 18	144	76	.5	19	.02	38	21	11	.0	190	20	1.5	6.0	213	5.3
Oct. 20	Oct. 31	151	86	.6	15	.04	42	19	12	.0	206	22	1.0	6.5	220	4.4
Nov. 1	Nov. 8	50	41	.8	19	.04	41	19	14	.0	214	26	.5	4.3	223	4.8
Nov. 9	Nov. 19	30	41	1.0	17	.03	35	16	8.0	.0	174	14	.3	7.5	185	5.8
Nov. 20	Nov. 30	30	27	.9	16	.05	36	17	11	.0	182	27	2.5	3.8	196	5.9
Dec. 1	Dec. 10	50	54	1.1	17	.32	37	19	11	.0	188	28	2.5	6.2	217	6.6
Dec. 11	Dec. 20	25	24	1.0	10	.11	35	18	13	.0	176	27	2.0	4.5	190	5.2
Dec. 21	Dec. 25	10.0	24	2.4	18	.28	37	24	16	.0	225	39	2.0	6.0	244	2.9
Jan. 1	Jan. 10	200	125	.6	19	1.0	35	16	16	.0	218	27	3.0	5.0	210	4.5
Jan. 11	Jan. 20	475	152	.3	26	2.2	36	18	9.8	.0	185	35	2.7	4.0	237	6.2
Jan. 21	Jan. 31	300	154	.5	26	1.4	32	14	17	.0	140	25	2.7	4.5	203	9.1
Feb. 2	Feb. 9	96	44	.4	21	.9	39	17	8.8	.0	180	30	2.7	5.2	218	4.2
Feb. 10	Feb. 18	80	59	.7	30	.44	41	18	12	.0	205	31	2.5	5.0	239	4.9
Feb. 19	Feb. 28	182	112	.6	15	.26	39	16	8.8	.0	183	22	3.2	6.0	207	5.8
Mar. 1	Mar. 10	110	110	1.7	16	.25	33	15	12	.0	151	19	5.0	3.3	188	6.5
Mar. 11	Mar. 20	190	147	.8	18	.61	35	16	10	.0	175	26	4.0	3.3	192	7.1
Mar. 21	Mar. 31	195	177	.9	17	.61	34	14	13	.0	176	26	5.0	2.8	193	7.5
Apr. 1	Apr. 10	250	188	.7	18	.35	32	13	7.0	.0	141	21	2.8	2.5	180	9.8
Apr. 11	Apr. 20	40	40	1.0	14	.22	24	10	7.9	.0	121	22	2.4	2.5	144	12.9
Apr. 21	Apr. 30	40	37	.9	8.4	.28	38	10	12	.0	138	24	1.1	6.5	170	11.9
May 1	May 10	45	45	1.0	10	.12	33	13	9.2	.0	163	22	.9	2.5	176	9.1
May 11	May 20	55	52	.9	10	.34	31	11	8.7	.0	151	32	2.0	3.5	213	7.8
May 21	May 31	165	166	1.0	15	.7	32	16	8.7	.0	158	22	1.4	2.3	176	8.2
June 1	June 10	170	171	1.0	14	.13	34	15	6.9	.0	161	19	2.3	2.5	188	8.6
June 11	June 20	250	227	.9	14	.62	40	17	8.4	.0	173	16	1.2	2.3	200	10.6
June 21	June 30	210	177	.8	16	.32	45	17	8.7	.0	190	28	1.5	3.5	218	9.1
July 1	July 10	150	135	.9	20	.12	44	19	13	.0	207	37	2.5	3.0	227	8.3
July 11	July 20	400	294	.7	24	.66	40	15	10	.0	163	28	2.4	3.5	211	11.5
July 21	July 31	175	101	.6	31	.5	45	17	15	.0	207	30	1.8	3.8	239	13.4
Mean		173	119	.8	18	.46	36	16	11	.0	175	25	2.2	4.4	203	....
Per ct. of anhydrous residue		....	....	....	9.0	[a].3	18.1	8.0	5.5	43.2	.....	12.6	1.1	2.2	.....	....

[a] Fe_2O_3.

TABLE 40.—*Mineral analyses of water from Mississippi River near Chester, Ill.*

[Parts per million unless otherwise stated.]

Date (1906–7). From—	Date (1906–7). To—	Turbidity.	Suspended matter.	Coefficient of fineness.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.
Aug. 1	Aug. 10	1,400	743	0.5	6.2	0.30	46	15	30	0.0	146	93	0.8	11	320
Aug. 11	Aug. 20	1,525	705	.5	27	.14	38	14	27	.0	145	52	2.1	9.5	237
Aug. 21	Aug. 30	1,875	857	.4	33	.30	40	16	17	.0	145	47	2.5	10.0	245
Aug. 31	Sept. 9	1,650	929	.6	16	.04	39	13	20	.0	161	55	2.5	12	256
Sept. 11	Sept. 19	840	560	.7	24	.25	40	17	26	.0	164	48	1.4	10	249
Sept. 20	Sept. 29	980	1,042	1.1	19	.16	47	17	19	.0	167	55	1.2	16	260
Sept. 30	Oct. 9	766	615	.8	16	.05	39	17	24	.0	150	40	1.5	11	228
Oct. 10	Oct. 19	1,100	733	.7	19	.08	46	21	24	.0	190	54	2.0	10	266
Oct. 22	Oct. 31	530	290	.5	22	.08	53	22	25	.0	236	58	1.2	12	306
Nov. 1	Nov. 9	540	377	.7	22	.02	52	19	28	.0	219	66	1.5	15	316
Nov. 15	Nov. 19	710	498	.7	24	.04	53	23	22	.0	200	78	1.7	13	310
Nov. 20	Nov. 28	634	440	.7	19	.20	42	17	15	.0	180	54	3.5	10	254
Dec. 1	Dec. 10	293	228	.8	20	.37	43	19	15	.0	195	49	2.0	10	265
Dec. 11	Dec. 20	220	254	1.2	17	1.30	46	20	16	.0	192	54	2.0	9.5	271
Dec. 22	Dec. 31	194	151	.8	15	.12	52	.....	24	.0	241	55	4.0	11	301
Jan. 1	Jan. 10	325	235	.7	20	.56	43	18	16	.0	205	52	3.5	10	271
Jan. 11	Jan. 19	450	355	.8	20	1.1	39	15	18	.0	175	51	2.5	7.0	260
Jan. 21	Jan. 31	850	561	.7	35	1.2	35	10.0	18	.0	117	42	1.2	5.7	222
Feb. 1	Feb. 9	310	213	.7	21	1.2	33	13	22	.0	148	36	7.0	6.2	214
Feb. 10	Feb. 18	181	132	.7	23	.47	46	17	22	.0	189	49	5.0	12	277
Feb. 21	Feb. 28	587	496	.8	24	.33	47	16	23	.0	187	63	4.0	12	304
Mar. 1	Mar. 10	580	621	1.1	21	.35	42	17	26	.0	161	55	5.0	7.5	266
Mar. 11	Mar. 20	390	274	.7	34	.45	42	13	19	.0	146	44	3.0	18	257
Mar. 21	Mar. 31	800	649	.7	19	.26	38	13	19	.0	166	53	4.0	5.8	238
Apr. 21	Apr. 30	445	280	.6	20	1.2	47	20	12	.0	166	65	2.0	5.0	256
June 1	June 10	2,000	1,788	.8	23	.13	44	16	14	.....	156	64	2.4	7.0	284
June 11	June 20	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
June 21	June 30	1,300	1,455	1.1	22	.41	59	16	24	.0	178	66	2.4	6.5	296
July 1	July 10	1,320	1,277	1.0	26	.26	48	14	21	.0	173	62	2.5	7.0	294
July 11	July 20	2,300	1,807	.8	25	.18	50	17	13	.0	170	81	2.0	7.0	304
July 21	July 31	634	482	.8	24	.14	47	14	21	.0	166	54	5.2	7.5	250
Mean		858	634	.8	22	.39	44	16	21	.0	174	56	2.7	9.8	269
Per ct. of anhydrous residue		.....	.....	.....	8.5	[a].2	17.1	6.2	8.2	33.2	.....	21.8	1.0	3.8	....

[a] Fe_2O_3.

TABLE 41.—*Mineral analyses of water from Vermilion River near Danville, Ill.*

[Parts per million unless otherwise stated.]

Date (1906–7).		Turbidity.	Suspended matter.	Coefficient of fineness.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.
From—	To—														
Aug. 2	Aug. 10	135	54	0.4	20	0.40	48	31	27	0.0	272	39	0.7	5.7	299
Aug. 11	Aug. 20	300	147	.5	18	.5	38	24	11	.0	193	27	2.7	3.2	216
Aug. 22	Aug. 30	425	201	.5	19	.20	36	15	15	.0	163	25	4.5	4.5	222
Aug. 31	Sept. 9	117	59	.5	15	.10	56	28	15	.0	241	36	3.0	5.0	282
Sept. 10	Sept. 19	50	38	.8	13	.30	44	28	8.7	.0	285	38	.8	5.0	267
Sept. 20	Sept. 29	142	68	.5	20	.12	49	24	15	.0	282	32	1.8	7.0	264
Sept. 30	Oct. 9	90	44	.5	11	.07	52	26	18	.0	270	36	1.2	5.0	275
Oct. 10	Oct. 19	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Oct. 20	Oct. 29	20	18	.9	12	.04	59	36	23	.0	326	41	.6	7.5	322
Oct. 30	Nov. 8	10.0	5.2	.5	13	.10	63	36	20	.0	350	46	.3	6.5	342
Nov. 9	Nov. 19	20	7.8	.4	6.2	.03	60	36	21	.0	330	44	.6	7.5	318
Nov. 20	Nov. 30	161	155	1.0	16	.05	53	25	10.0	.0	220	46	8.0	3.5	279
Dec. 1	Dec. 10	125	78	.6	21	.06	56	26	12	.0	254	47	14	4.2	302
Dec. 11	Dec. 20	50	61	1.2	12	.17	56	27	8.0	.0	236	42	16	4.8	301
Dec. 21	Dec. 31	40	47	1.2	10.0	.24	58	28	14	.0	275	46	12	4.5	314
Jan. 1	Jan. 10	270	258	1.0	19	.37	39	22	14	.0	189	67	12	4.7	254
Jan. 11	Jan. 19	296	255	.9	17	.6	43	18	13	.0	190	47	5.5	3.0	245
Jan. 21	Jan. 31	90	57	.6	20	1.1	50	22	13	.0	189	41	16	5.0	263
Feb. 1	Feb. 9	10.0	6.0	.6	15	.16	62	27	13	.0	265	47	16	5.2	330
Feb. 10	Feb. 18	45	21	.5	18	.09	56	23	14	.0	240	55	12	5.0	316
Feb. 20	Feb. 28	10.0	12	1.2	8.4	.13	57	24	14	.0	247	50	16	5.0	299
Mar. 1	Mar. 10	7.0	8.6	1.2	11	.13	49	23	14	.0	243	39	8.0	3.8	279
Mar. 11	Mar. 20	230	164	.7	15	.70	49	20	13	.0	180	50	12	3.5	256
Mar. 21	Mar. 31	160	45	.3	15	.54	48	22	9.3	.0	207	48	24	4.8	250
Apr. 1	Apr. 10	25	18	.7	14	.18	55	25	9.3	.0	236	44	24	4.0	266
Apr. 11	Apr. 20	5.0	4.4	.9	8.6	.23	54	21	10.0	.0	242	45	19	2.5	264
Apr. 21	Apr. 30	19	18	1.0	4.7	1.3	56	35	8.7	.0	247	52	11	3.0	295
May 1	May 10	45	25	.6	18	.26	50	18	9.5	.0	227	45	24	3.8	274
May 11	May 20	25	22	.9	9.2	.15	56	24	9.2	.0	243	40	24	3.8	288
May 21	May 31	35	36	1.0	11	.15	56	28	9.2	.0	239	44	24	3.8	276
June 1	June 10	330	251	.8	13	.18	50	26	8.1	.0	175	37	20	4.2	230
June 11	June 20	65	56	.9	11	.25	63	26	8.7	.0	250	42	16	4.3	304
June 21	June 30	100	29	.3	14	.57	61	24	8.6	.0	245	34	10.0	3.0	258
July 1	July 10	70	68	1.0	17	.25	65	25	6.7	.0	267	37	16	5.0	301
July 11	July 20	460	487	1.1	13	.24	64	21	8.2	.0	221	34	18	3.3	290
July 21	July 31	55	48	.9	17	.23	64	25	8.9	.0	265	35	24	4.0	285
Mean		115	82	.8	14	.29	54	25	13	.0	243	42	12	4.5	281
Per ct. of anhydrous residue		.....	.....	.....	4.9	[a].1	19.0	8.8	4.6	42.1	.....	14.7	4.2	1.6	....

[a] Fe_2O_3.

TABLE 42.—*Mineral analyses of water from Embarrass River near Charleston, Ill.*

[Parts per million unless otherwise stated.]

Date (1906–7).		Turbidity.	Suspended matter.	Coefficient of fineness.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.
From—	To—														
Aug. 1	Aug. 10	215	184	0.8	27	0.35	48	25	20	0.0	251	31	2.8	7.5	297
Aug. 11	Aug. 20	268	172	.6	21	.20	39	18	12	.0	182	22	2.1	4.2	230
Aug. 22	Aug. 30	400	167	.4	22	.06	36	18	16	.0	182	24	3.5	2.0	226
Aug. 31	Sept. 9	100	41	.4	18	.08	57	29	15	.0	282	28	1.7	5.5	282
Sept. 10	Sept. 19	214	78	.4	21	.30	38	20	7.3	.0	190	22	1.4	3.5	214
Sept. 20	Sept. 27	220	94	.4	17	.45	38	18	11	.0	192	23	2.5	5.5	212
Sept. 30	Oct. 9	182	108	.6	19	.04	56	28	28	.0	287	27	3.0	5.0	316
Oct. 10	Oct. 19	70	42	.6	11	.16	58	31	16	.0	315	36	1.5	5.0	310
Oct. 20	Oct. 28	30	20	.7	10.0	.14	61	33	21	.0	322	32	0.5	7.2	291
Oct. 29	Nov. 10	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Nov. 11	Nov. 19	100	64	.6	6.4	.10	59	39	16	.0	320	30	0.4	7.2	293
Nov. 20	Nov. 30	200	178	.9	18	.06	37	22	11	.0	246	18	5.0	5.3	258
Dec. 1	Dec. 10	160	175	1.1	26	.20	54	25	18	.0	280	32	8.0	4.0	283
Dec. 11	Dec. 20	144	144	1.0	13	.09	54	26	11	.0	257	26	8.0	5.5	277
Dec. 21	Dec. 31	224	361	1.1	12	.32	57	31	10.0	.0	286	34	8.0	6.0	300
Jan. 1	Jan. 10	280	352	1.2	17	.57	43	21	13	.0	219	34	9.0	5.0	236
Jan. 11	Jan. 18	275	292	1.1	30	.80	38	16	15	.0	200	35	7.0	4.2	254
Jan. 21	Jan. 31	100	106	1.1	32	3.6	41	20	10.0	.0	200	22	8.0	4.2	232
Feb. 1	Feb. 8	20	21	1.0	11	.15	55	24	8.0	.0	253	33	6.0	5.0	271
Feb. 10	Feb. 18	25	37	1.5	19	.13	52	21	13	.0	260	43	8.5	5.0	291
Feb. 19	Feb. 28	25	31	1.2	14	.08	54	23	14	.0	267	33	8.0	5.0	281
Mar. 1	Mar. 10	25	35	1.4	11	.26	52	24	13	.0	250	41	8.0	4.5	289
Mar. 11	Mar. 20	800	1,014	1.3	18	.24	45	18	11	.0	173	39	10.0	7.5	237
Mar. 21	Mar. 31	100	90	.9	15	.23	51	25	15	.0	242	39	16	4.3	278
Apr. 1	Apr. 10	10.0	18	1.8	9.0	.26	54	24	9.6	.0	249	48	16	5.5	269
Apr. 11	Apr. 20	8.0	10.0	1.2	10.0	.16	52	25	9.9	.0	250	34	14	4.5	264
Apr. 21	Apr. 30	70	41	.6	11	.45	49	29	6.3	.0	225	32	9.2	5.5	256
May 1	May 10	20	15	.8	13	.12	52	24	15	.0	267	32	12	5.5	285
May 11	May 20	30	33	1.1	8.2	.16	49	22	12	.0	256	35	10.0	7.3	281
May 21	May 31	30	33	1.1	5.0	.50	50	23	10.0	.0	250	31	10.0	4.3	276
June 1	June 10	200	162	.8	16	.36	50	24	13	.0	228	25	13	3.8	267
June 11	June 20	90	88	1.0	17	.34	65	29	7.5	.0	284	32	6.0	3.5	277
June 21	June 30	200	149	.7	16	.23	57	21	11	.0	281	29	13	4.5	269
July 1	July 10	80	65	.8	20	.15	66	25	13	.0	280	26	18	4.5	312
July 11	July 20	422	380	.9	22	.26	50	21	13	.0	217	27	7.0	3.0	243
July 21	July 31	100	93	.9	26	.21	64	24	14	.0	270	30	10.0	3.2	301
Mean		155	140	.9	17	.34	51	24	13	.0	249	31	7.6	4.9	270
Per ct. of anhydrous residue		.....	.....	.....	6.3	[a].2	18.8	8.9	4.8	45.0	.....	11.4	2.8	1.8	....

[a] Fe_2O_3.

TABLE 43.—*Mineral analyses of water from Embarrass River near Lawrenceville, Ill.*

[Parts per million unless otherwise stated.]

Date (1906–7). From—	To—	Turbidity.	Suspended matter.	Coefficient of fineness.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.
Aug. 1	Aug. 10	280	52	0.5	24	0.30	42	22	29	0.0	207	33	1.2	26	278
Aug. 11	Aug. 20	220	111	.5	15	.14	33	18	18	.0	150	23	2.4	23	231
Aug. 21	Aug. 30	268	103	.4	17	.30	33	18	32	.....	123	26	1.5	45	240
Aug. 31	Sept. 16	148	89	.6	15	.20	42	22	19	.0	205	24	.8	26	251
Sept. 17	Sept. 26	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Sept. 27	Oct. 12	.....	.....	.....	.....	.....	.....	19	.....	.....	.....	.....	.....	.....	.....
Oct. 13	Oct. 19	20	19	1.0	18	.08	59	27	49	.0	274	45	7.0	64	426
Oct. 20	Oct. 29	20	15	.8	16	.10	55	25	43	.0	270	36	.3	61	371
Oct. 30	Nov. 8	20	8.0	.4	11	.10	60	34	87	.0	305	49	.2	114	472
Nov. 9	Nov. 18	20	7.4	.4	16	.05	72	31	48	.0	335	50	5.5	75	468
Nov. 20	Nov. 30	220	98	.5	15	.20	66	.....	55	.0	229	64	.3	88	458
Dec. 14	Dec. 20	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Dec. 21	Dec. 31	103	76	.7	21	.32	49	23	20	.0	227	46	5.0	20	308
Jan. 1	Jan. 10	214	78	.4	20	3.7	19	8.5	18	.0	100	27	2.5	9.5	166
Jan. 11	Jan. 20	161	89	.6	31	1.4	28	16	17	.0	136	36	4.5	9.2	205
Jan. 21	Jan. 31	159	50	.3	25	1.7	24	9.5	17	.0	104	30	4.0	8.2	174
Feb. 2	Feb. 9	45	34	.8	14	.22	46	20	27	.0	203	43	2.0	20	268
Feb. 10	Feb. 18	12	13	1.1	11	.13	52	22	21	.0	234	44	6.0	24	284
Feb. 19	Feb. 28	8.0	11	1.2	18	.07	54	24	25	.0	244	54	6.0	32	342
Mar. 1	Mar. 10	50	45	.9	14	.15	52	18	33	.0	205	29	4.2	46	342
Mar. 11	Mar. 20	280	177	.6	22	2.2	26	10.0	15	.0	111	38	9.2	14	192
Mar. 21	Mar. 31	120	54	.4	19	.78	44	16	19	.0	198	39	14	16	274
Apr. 1	Apr. 10	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Apr. 11	Apr. 20	15	13	.9	13	.13	55	26	28	.0	240	42	3.3	40	325
Apr. 21	Apr. 30	112	54	.5	10	.32	45	24	29	.0	243	43	2.6	51	296
May 1	May 10	210	109	.5	13	.62	37	12	22	.0	143	35	2.4	28	238
May 11	May 20	80	44	.6	11	.15	42	17	31	.0	183	52	3.2	40	287
May 21	May 31	120	94	.8	19	.30	34	15	17	.0	141	34	1.5	26	235
June 1	June 10	200	107	.5	9.2	.29	26	9.3	13	.0	91	17	2.7	12	120
June 11	June 20	100	70	.7	18	.59	48	23	17	.0	187	28	2.0	19	251
June 21	June 30	220	128	.6	18	.90	51	18	19	.0	190	26	1.4	36	255
July 1	July 10	43	41	1.0	17	.14	55	20	20	.0	231	25	7.0	18	275
July 11	July 20	181	123	.7	13	.11	39	18	28	.0	158	21	2.1	38	246
July 21	July 31	68	60	.9	15	.22	45	17	15	.0	170	24	6.0	22	222
Mean.....		118	66	.7	17	.53	44	19	28	.0	195	35	3.7	35	283
Per ct. of anhydrous residue...		.....	.....	.....	6.1	*a* .3	15.8	6.8	10.0	34.5	.....	12.6	1.3	12.6	....

a Fe_2O_3.

TABLE 44.—*Mineral analyses of water from Little Wabash River near Carmi, Ill.*

[Parts per million unless otherwise stated.]

Date (1906–7).		Turbidity.	Suspended matter.	Coefficient of fineness.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.	Mean gage height (feet).
From—	To—															
Aug. 1	Aug. 10	20	9.2	0.5	38	0.20	27	15	18	0.0	171	19	0.8	.....	219	....
Aug. 11	Aug. 20	40	25	.6	22	.20	31	16	22	.0	160	26	1.9	12	211	....
Aug. 21	Aug. 30	144	55	.4	28	.25	23	8.3	14	.0	97	25	1.5	14	174	....
Aug. 31	Sept. 9	142	60	.4	38	.32	21	13	14	.0	91	22	1.5	6.3	163	....
Sept. 10	Sept. 19	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	....
Sept. 20	Sept. 29	90	38	.4	18	.30	23	13	15	.0	95	24	2.0	5.5	147	....
Sept. 30	Oct. 9	127	64	.5	19	.35	16	10	14	.0	76	21	1.5	9.0	138	1.3
Oct. 10	Oct. 18	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.7
Oct. 20	Oct. 29	70	23	.3	30	2.0	22	9.3	21	.0	93	32	.6	6.5	188	0.6
Oct. 30	Nov. 7	30	19	.6	26	.6	24	14	16	.0	118	44	.9	11	187	0.5
Nov. 9	Nov. 19	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.6
Nov. 20	Nov. 30	430	170	.4	18	.7	13	4.0	6.4	.0	39	19	3.0	1.0	111	6.4
Dec. 1	Dec. 9	182	68	.4	27	1.5	17	9.1	16	.0	69	33	3.5	8.8	153	4.5
Dec. 12	Dec. 20	273	109	.4	39	3.7	15	3.8	15	.0	52	23	2.5	6.5	185	8.4
Dec. 21	Dec. 31	151	77	.5	39	3.7	16	5.3	16	.0	64	38	2.5	5.5	184	7.5
Jan. 1	Jan. 10	220	67	.3	31	9.9	7.8	6.2	15	.0	54	26	6.0	4.2	140	17.1
Jan. 11	Jan. 20	94	10.0	.9	35	3.2	10.0	3.8	13	.....	51	31	1.2	4.0	159	19.8
Jan. 21	Jan. 31	60	21	.4	17	.40	11	5.2	10.0	.0	44	30	4.0	5.5	138	26.0
Feb. 1	Feb. 9	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	21.6
Feb. 10	Feb. 18	40	20	.5	21	2.8	25	9.6	16	.0	108	42	2.0	7.5	193	5.8
Feb. 19	Feb. 28	35	29	.8	15	.9	32	12	21	.0	126	51	1.5	16	219	0.9
Mar. 1	Mar. 10	100	94	.9	24	2.2	28	15	25	.0	104	74	3.0	11	239	3.5
Mar. 11	Mar. 20	330	198	.6	25	4.9	8.5	6.7	19	.0	57	35	1.5	7.3	187	11.8
Mar. 21	Mar. 31	145	34	.2	48	6.5	15	6.7	18	.....	69	38	2.7	6.0	240	22.3
Apr. 1	Apr. 10	60	26	.4	24	2.3	36	15	14	.....	126	51	2.8	8.0	227	5.8
Apr. 11	Apr. 20	60	26	.4	19	1.3	36	17	17	.0	153	52	1.8	8.3	236	1.9
Apr. 21	Apr. 30	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	1.8
May 1	May 10	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	3.7
May 11	May 20	140	110	.8	25	1.1	21	11	12	.0	86	43	2.5	9.0	182	2.7
May 21	May 31	155	125	.8	18	.74	22	7.9	11	.0	74	30	1.2	7.0	151	3.1
June 1	June 10	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	8.8
June 11	June 20	155	110	.7	26	1.1	19	7.7	10.0	.0	64	14	1.5	5.5	149	9.8
June 21	June 30	220	143	.7	22	4.9	20	4.8	12	.0	102	24	2.4	6.0	153	4.7
July 1	July 10	110	65	.6	14	1.6	18	3.9	8.1	.0	80	22	1.7	6.0	134	2.0
July 11	July 20	120	100	.8	15	.19	18	6.4	11	.0	83	22	1.2	6.5	137	1.7
July 21	July 31	160	84	.5	33	1.7	14	4.8	10.0	.0	53	19	1.5	5.0	150	....
Mean		135	68	.5	26	2.0	20	9.1	15	.0	88	32	2.1	7.5	176	....
Per ct. of anhydrous residue		.....	.....	.....	16.5	[a]1.8	12.6	5.8	9.5	27.5	.....	20.3	1.3	4.7	.....	....

[a] Fe_2O_3.

TABLE 45.—*Mineral analyses of water from Cache River near Mounds, Ill.*

[Parts per million unless otherwise stated.]

Date (1906–7).		Turbidity.	Suspended matter.	Coefficient of fineness.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.	Mean gage height (feet).
From—	To—															
Aug. 1	Aug. 10	210	94	0.4	4.6	0.20	26	10.0	13	0.0	121	4.3	1.0	7.2	166	....
Aug. 11	Aug. 20	220	75	.3	20	1.0	18	7.4	29	.0	93	20	0.9	5.0	141	....
Aug. 21	Aug. 30	155	61	.3	31	.60	22	7.0	38	.0	90	35	1.0	15	211	....
Aug. 31	Sept. 9	130	64	.5	16	.17	22	9.1	20	.0	94	14	1.0	6.5	139	....
Sept. 10	Sept. 19	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	....
Sept. 20	Sept. 29	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	3.8
Sept. 30	Oct. 9	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	7.4
Oct. 10	Oct. 19	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	8.4
Oct. 20	Oct. 31	40	15	.4	9.2	.26	33	13	17	.0	159	27	.7	7.0	190	3.2
Nov. 1	Nov. 8	40	42	1.0	22	.19	42	8.7	25	.0	211	44	.6	19	284	2.9
Nov. 15	Nov. 21	155	68	.4	26	.25	19	3.8	39	.0	108	43	1.5	23	244	3.0
Nov. 22	Nov. 30	168	58	.3	28	.80	19	4.5	37	.0	85	35	2.0	14	229	8.5
Dec. 1	Dec. 10	273	175	.6	23	2.8	9.7	3.6	11	.0	59	14	1.2	6.0	129	5.2
Dec. 11	Dec. 20	90	20	.2	22	3.2	9.7	3.0	7.4	.0	41	18	3.0	3.0	126	7.7
Dec. 21	Dec. 31	50	152	3.0	28	2.8	9.2	6.4	14	.0	59	17	2.7	3.0	117	11.5
Jan. 1	Jan. 10	182	53	.3	39	6.5	8.3	3.1	17	.0	72	19	1.2	3.7	170	17.3
Jan. 11	Jan. 20	112	35	.3	29	5.2	12	4.0	11	.0	62	18	2.7	4.7	142	23.6
Jan. 21	Jan. 31	50	23	.5	24	2.8	12	6.3	14	.0	66	19	2.4	4.0	121	24.5
Feb. 1	Feb. 9	40	34	.8	23	2.5	13	3.7	12	.0	58	22	3.5	4.5	129	19.4
Feb. 10	Feb. 17	20	12	.6	19	4.8	15	5.6	11	.0	74	13	1.0	6.7	115	13.4
Feb. 19	Feb. 28	175	93	.5	21	4.9	14	3.9	8.2	.0	70	16	6.0	5.5	121	7.3
Mar. 1	Mar. 10	100	36	.4	33	.....	12	5.4	13	.0	42	15	1.2	3.0	138	8.8
Mar. 11	Mar. 20	290	73	.3	43	4.5	15	1.5	7.0	.0	57	9.2	2.4	4.0	169	15.8
Mar. 21	Mar. 31	130	48	.4	21	7.4	16	4.0	9.0	.0	64	16	1.2	3.8	119	17.5
Apr. 1	Apr. 10	340	84	.2	24	2.6	18	5.6	8.7	.0	69	15	7.0	3.3	125	10.1
Apr. 11	Apr. 20	55	34	.6	18	3.4	16	6.3	9.0	.0	94	13	.6	4.5	138	5.0
Apr. 21	Apr. 31	45	30	.7	10.0	1.5	23	8.5	6.9	.0	96	12	1.5	4.5	118	6.0
May 1	May 10	145	117	.8	12	1.5	28	5.8	19	.0	104	36	1.0	13	.....	9.2
May 11	May 20	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	14.8
May 21	May 31	125	125	1.0	22	.58	16	3.5	7.0	.0	52	12	.6	4.0	92	10.3
June 1	June 10	195	78	.4	11	.56	20	5.3	8.6	.0	69	27	1.4	5.3	100	11.7
June 11	June 20	149	73	.5	18	3.8	25	9.0	3.9	.0	94	17	1.3	3.0	140	18.8
June 21	June 30	65	38	.6	20	4.5	24	8.5	6.2	.0	85	11	8.0	4.5	131	16.2
July 1	July 10	103	76	.7	15	.20	23	5.9	8.8	.0	97	9.7	2.0	4.5	116	8.2
July 11	July 20	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	7.1
July 21	July 31	160	102	.6	24	2.6	25	9.0	13	.0	100	10.0	.7	10.0	158	11.6
Mean.....		134	66	.6	22	2.5	19	6.0	15	.0	85	19	2.1	6.8	149	....
Per ct. of anhydrous residue..		.....	.....	.....	16.2	[a]2.7	14.0	4.4	11.1	31.1	.....	14.0	1.5	5.0	.....	....

[a] Fe_2O_3.

TABLE 46.—*Average quality of waters of some rivers in Illinois.*

[Parts per million.]

Source and location of sampling station.	Turbidity.	Suspended matter.	Coefficient of fineness.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.
Reservoir, Cartter, Ill.	72	33	0.5	16	1.9	9.0	3.6	8.6	0.0	34	16	2.1	5.2	92
Reservoir, Marion, Ill.	97	43	.5	13	.93	15	8.2	17	.0	51	45	1.7	8.3	140
Reservoir, Cypress, Ill.	155	59	.5	29	3.7	18	7.0	13	.0	67	33	2.2	6.8	165
Reservoir, Joppa, Ill.	116	66	.5	22	3.5	10	4.0	9.0	.0	43	19	1.9	4.3	111
Rock River, Rockford, Ill.	134	92	.7	15	.44	45	25	10	.0	252	22	4.1	4.6	250
Rock River, Sterling, Ill.	229	236	1.2	15	.31	49	27	12	.0	263	25	3.8	5.5	267
Kankakee River, Kankakee, Ill.	50	32	.7	15	.27	58	21	12	.0	215	57	4.1	4.9	288
Fox River, Elgin, Ill.	34	23	.7	12	.15	51	30	11	.0	268	38	2.4	5.2	290
Fox River, Ottawa, Ill.	94	87	1.2	11	.20	60	32	14	.0	275	61	4.9	7.9	335
Vermilion River (of Illinois), Streator, Ill.	107	78	.7	14	.22	55	29	18	.0	241	68	12	6.9	325
Sangamon River, Decatur, Ill.	126	87	.7	19	.27	55	26	14	.0	268	35	8.5	5.4	293
Sangamon River, Springfield Ill.	74	39	.8	16	.32	52	24	16	.0	247	37	3.4	7.5	276
Sangamon River, Chandlerville, Ill.	154	102	.7	15	.32	52	25	15	.0	255	36	6.1	7.6	282
Illinois River, Lasalle, Ill.	159	136	.8	12	.21	50	22	16	.0	203	50	6.6	13	278
Illinois River, Peoria, Ill.	43	26	.8	12	.21	49	21	17	.0	198	48	7.8	13	271
Illinois River, Kampsville, Ill.	188	145	.8	12	.27	47	20	18	.0	202	42	4.3	15	267
Kaskaskia River, Shelbyville, Ill.	110	84	.9	16	.23	53	26	13	.0	262	34	6.9	5.6	279
Kaskaskia River, Carlyle, Ill.	184	126	.7	17	.39	47	20	14	.0	213	34	4.8	6.9	248
Muddy River, Murphysboro, Ill.	245	129	.5	24	2.1	25	12	20	.0	72	72	2.0	13	225
Mississippi River, Moline, Ill.	117	106	.9	16	.39	33	13	10	.0	152	24	1.8	3.7	179
Mississippi River, Quincy, Ill.	173	119	.8	18	.46	36	16	11	.0	175	25	2.2	4.4	203
Mississippi River, Chester, Ill.	858	634	.8	22	.39	44	16	21	.0	174	56	2.7	9.8	269
Vermilion River (of Wabash), Danville, Ill.	115	82	.8	14	.29	54	25	13	.0	243	42	12	4.5	281
Embarrass River, Charleston, Ill.	155	140	.9	17	.34	51	24	13	.0	249	31	7.6	4.9	270
Embarrass River, Lawrenceville, Ill.	118	66	.7	17	.53	44	19	28	.0	195	35	3.7	35	283
Little Wabash River, Carmi, Ill.	135	68	.5	26	2.0	20	9.1	15	.0	88	32	2.1	7.5	176
Cache River, Mounds, Ill.	134	66	.6	22	2.5	19	6.0	15	.0	85	19	2.1	6.8	149

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DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

WATER-SUPPLY PAPER 240

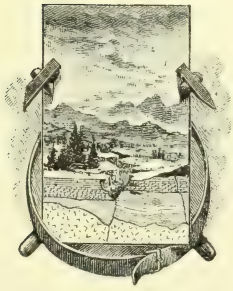
GEOLOGY AND WATER RESOURCES

OF THE

SAN LUIS VALLEY, COLORADO

BY

C. E. SIEBENTHAL



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GEOLOGY AND WATER RESOURCES OF THE SAN LUIS VALLEY, COLORADO.

By C. E. Siebenthal.

INTRODUCTION.

SCOPE OF REPORT.

In the preparation of this report three objects have been kept in view:

1. To present such a summary of the geologic conclusions of previous workers together with the observations of the writer as would give to the reader a comprehensive view of the geology of the San Luis Valley and the surrounding rim and enable him to understand the relation of the artesian basin to the geologic structure.

2. To give a description of the artesian basin, its development, and its prospects.

3. Finally, to make accessible to the reader such information in regard to climate, agriculture, irrigation, and water resources as is available and of general interest.

DATE OF REPORT.

The field work in the San Luis Valley was completed in 1904, and the report thereon was prepared in 1906. Untoward circumstances have intervened to prevent the publication of the report until the present. It is to be understood, therefore, that the description of the development and prospects of the artesian basin refers to conditions at the close of field work in 1904.

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Obligations are also due to Prof. W. A. Converse, of the Dearborn Drug and Chemical Company, of Chicago, Ill., for analyses of various well waters, duly credited in the table of analyses, several made especially for this report; to Dr. W. P. Headden, of the Colorado Agricultural College, for various analyses of San Luis waters, also credited in the report; and to Mr. P. F. Lund, of the Denver and Rio Grande Railroad, for data concerning various wells sunk by that company in the valley.

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GEOGRAPHY.

LOCATION AND CHARACTER.

The San Luis Valley, having an area comparable to the State of Connecticut, lies in the south-central part of Colorado (fig. 1), with a

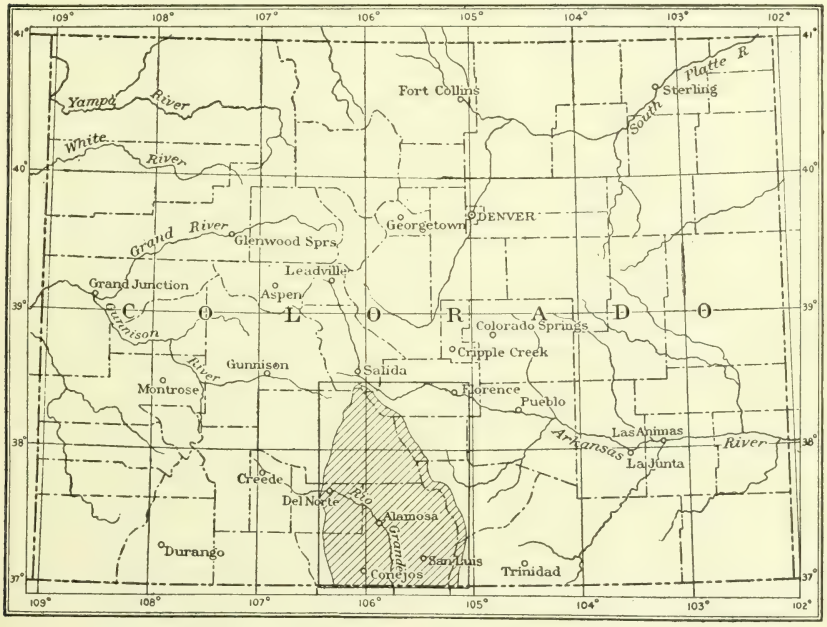


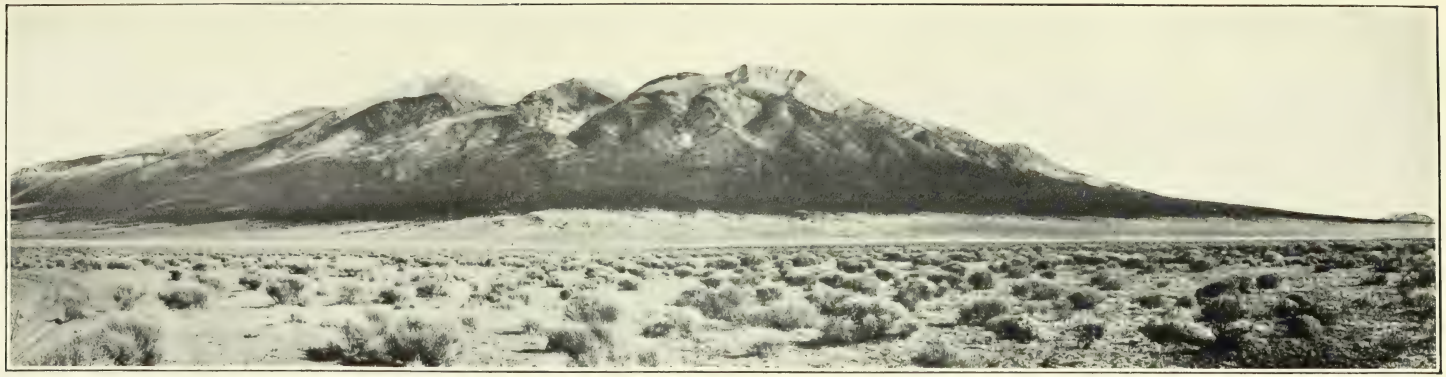
FIGURE 1.—Outline map of Colorado, showing location of San Luis Valley.

narrowed southern end reaching into New Mexico about 15 miles. The whole length of the valley from north to south is about 150 miles and its greatest width about 50 miles. The San Luis Hills, a series of basalt-capped table-topped mountains extending from Antonito in the direction of Fort Garland, separate the valley into two portions. It is with the northern part, containing the artesian basin, that we have to do. This portion of the valley is limited on the east by the majestic Sangre de Cristo Range, on the west by the Sawatch and Conejos ranges, and on the south by the San Luis Hills.

TOPOGRAPHY.

The accompanying topographic map is based on Hayden's geologic and topographic atlas of Colorado for the mountainous region, with the addition of certain details near the margin of the valley, but the valley portion is compiled by the writer from sketches in the field, aneroid readings, and the various railway and ditch profiles. A study of the map will give a very clear notion of the topography. The salient features are the bold Sangre de Cristo Range and the less abrupt Culebra Range on the east, the gentler eastward-sloping Sawatch and Conejos ranges on the west, the flat-topped San Luis Hills on the south, and the almost flat surface of the valley itself. As the map shows, the trough of the valley lies far east of the median axis—close under the Sangre de Cristo, in fact. From the trough the country rises to the foothills, more steeply eastward, very gently westward, at first not more than 3 to 6 feet to the mile, but gradually increasing until near the foothills the rise is quite perceptible to the eye. The extreme flatness of the valley is shown by the great distances for which the canals are constructed along straight lines. The Prairie ditch and the laterals of the Farmer's Union canal and the Del Norte canal run from 10 to 25 miles on straight east and west lines, with branches north and south at right angles.

So nearly level is the valley floor that its essential character entirely escapes one traveling over it, and it is only when brought out by a topographic map that it becomes clear. In such a map, however, the alluvial-fan structure of the valley floor is strikingly manifest. Each stream descending from the steeper slopes of the mountains to the valley has deposited its spreading fan of gravel and sand. Around the west and south sides of Blanca Peak (as shown in Pl. II, *A*) these alluvial fans are especially prominent. They are so close together that they coalesce along their lateral margins to form a steep, gravelly alluvial slope skirting the foot of the mountain. The streams coming down from the west range, having a much lower gradient, can carry neither such heavy material nor so much of it, and as a consequence have built up much flatter fans, though the form of the fans is no doubt chiefly due to the fact that, except for the surface veneer of gravel and sand, they were deposited in water, as shown by the continuity of the clay and sand beds of the Alamosa formation. However, La Jara, Alamosa, and Cat creeks have built up pronounced fan deltas. But the map shows at a glance that the Rio Grande has built the most extensive fan of all and, for the reason given above, the flattest. It is also clear that the trough of the valley lies so far to the east because the encroaching fan has pushed it there, and that the sluggish character of San Luis Creek has resulted from the filling in of its lower course by the same agency. Conejos River has built a long fan partly confined between the Mogotes Mountains and the



A. BLANCA PEAK FROM THE SOUTHWEST.

Showing alluvial slopes and characteristic vegetation.

B. CIRQUE AT HEAD OF ROCK CREEK.

Showing character of gathering grounds in the western ranges of streams delivering water to the artesian system.

San Luis Hills, and partly extending south of the San Luis Hills into New Mexico, and must have discharged or at least sent distributaries at times to the south of the San Luis Hills. Saguache Creek has likewise a fan delta, but one rather poorly developed. San Luis Creek, taking its source in Poncha Pass not much above the level of the valley itself, naturally could develop no fan.

The streams in the valley proper have cut their valleys to various depths, but all are shallow. The bank of the Rio Grande at Monte Vista, where the oldest terrace comes to the river, is 20 or 30 feet high. At Alamosa the bank is from 8 to 12 feet high. The other streams have banks varying from a few inches to 4 or 5 feet high.

At different places in the valley there are bluffs which are not now adjacent to streams but which represent the margins of abandoned courses of the streams in their wanderings over the alluvial fans and slopes after the emptying of the lake which filled the valley during the deposition of the Alamosa formation. Most of these are shown on the map. One passes through Sanford, two are near Henry station, and one northwest of Hooper. They vary in height, but are mostly not far from 10 feet.

Stretching from Washington Springs south to the mouth of Trinchera Creek is a bluff bank which culminates opposite the Hansen ranch and has for that reason been called the Hansen Bluff. It here reaches a height above the Rio Grande of 60 feet, as shown in Plate VII, *B*. The level country stretching away eastward from its top represents the level of the valley bottom at the time when the water cut down the divide in the San Luis Hills and began to drain the lake that originally occupied the center of the valley. The original course of the river was probably somewhat west of its present course, but the alluvial fans of the streams on the west side of the valley have continually pushed it eastward and caused it to undercut the bluff.

The following elevations have been compiled from various sources, railway levels, ditch levels, and aneroid readings:

Elevation of points in San Luis Valley.

	Feet.		Feet.		Feet.
Alamosa	7,536	Crestone	7,851	Henry	7,548
Alder	8,525	Davenport	8,158	Hooper	7,555
Antonito	7,878	Del Norte	7,870	Hot Springs	7,746
Baldy	7,609	Dune	7,538	Hunt Springs	7,670
Blanca	8,405	Freedom P. O. (Morgan)	7,630	La Garita P. O	7,900
Blanca Peak	[a]14,390	Garnett P. O	7,598	La Garita ranch house	7,630
Bowen S. H	7,660	Garland	7,926	La Garita station	7,540
Carnero	7,700	Granger	8,040	La Jara	7,599
Capulin	7,800	Hayes	7,527	La Veta Pass	9,232
Center	7,630	Haywood	7,746	Lockett P. O	7,575
Creede	8,842				

[a] This is the elevation given in Gannett's "Dictionary of altitudes" (Bull. U. S. Geol. Survey No. 274, 1906, p. 141). The elevation given on the map (14,490±) was determined by the Hayden Survey; Gannett's figure was recalculated from that.

Elevation of points in San Luis Valley—Continued.

	Feet.		Feet.		Feet.
Manassa	7,660	Poncha Pass	9,038	South Fork	8,178
McGinty	7,542	Romeo	7,725	Swede Corners	7,630
McIntyre Springs	7,520	Round Hill	8,666	Valley View Springs	8,390
Meadow ranch house	7,570	Russell Springs	7,640	Veteran S. H	7,600
Mirage P. O	7,670	Saguache	7,710	Villa Grove	7,951
Mirage station	7,607	Sanford	7,600	Wagon Creek Junction	8,261
Moffatt	7,558	Sangre de Cristo	8,390	Wagon Wheel Gap	8,439
Monte Vista	7,655	San Isabel P. O	7,560	Warner (or Forbes) S. H	7,590
Mortimer	8,094	San Luis Lakes	7,520	Washington Springs	7,534
Mosca	7,551	Santa Fe branch (at state line)	8,029	Willis	7,576
Orient mine	8,750	Soldiers' Home	7,630	Zapato	7,715
Orient station	8,659	South Farm ranch house	7,630		
Parma	7,606				

DRAINAGE.

The Rio Grande enters from the middle of the west side, pursues a southeasterly course to the San Luis Hills, and leaves through a defile in them. A number of tributary streams, notably Conejos River and La Jara, Alamosa, and Saguache creeks, flow down from the Conejos and Sawatch ranges, whose more gentle slopes give room for extensive drainage areas. Arms of the valley extend for some distance up the courses of the Conejos, the Rio Grande, and the Saguache, while a long, narrow arm, extending northward to Poncha Pass, the upper end being known as Homan's Park, is drained by San Luis Creek. The surface configuration of the valley is such that this creek should receive all the water entering the valley on either side, north of the Rio Grande, but as a matter of fact most of the drainage, especially that of the eastern range, is lost by seepage before it reaches the creek, or reaches it only in flood season. The creek itself in its lower course develops a series of wet-weather ponds and finally flows into the San Luis Lakes. The old overflow drainage course to the Rio Grande still exists but has been so blocked and concealed by incipient sand dunes as to be very difficult to trace except in its general features.

HYDROGRAPHY.

STREAM GAGINGS.

A gaging station has been maintained for many years at Del Norte, where the Rio Grande enters the San Luis Valley, and above the head-gate of the uppermost of the valley irrigation systems. Another one was maintained for a long period at Embudo, N. Mex., at the lower end of Embudo Canyon, into which the river flows just before crossing the Colorado-New Mexico line. From 1899 until 1904 a sta-

tion was also maintained at State Bridge, at the upper end of Embudo Canyon. This station, situated but a few miles below the cultivated area of the valley, was of great importance in determining the volume of water left in the river after the valley irrigation, and the discontinuance of this and the Embudo station is much to be regretted. Tables showing the monthly discharge at these stations and of Conejos River at Los Mogotes are subjoined.

Discharge of Rio Grande at Del Norte, 1889–1905.

[Drainage area, 1,400 square miles.]

Month.	1889.	1890.	1891.	1892.	1893.	1894.	1895.	1896.	1897.	1898.
	Sec.-ft.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*
January	.....	*a* 552	*a* 990	*b* 300	*a* 966	*a* 1,003	*a* 801	*a* 1,293	*ab* 1,000	*a, b* 1,377
February	.....	*a* 796	*a* 1,294	*b* 300	*a, b* 700	*a* 995	*a* 953	*a* 1,258	*ab* 1,000	*a, b* 1,472
March	.....	487	1,280	316	*a, b* 500	*a* 831	638	*a* 1,081	*ab* 1,000	*a, b* 1,471
April	.....	913	*a* 1,410	1,047	533	699	*a* 1,883	1,484	1,067	*a* 1,912
May	.....	4,331	3,285	2,605	1,944	1,798	2,116	2,374	3,537	2,722
June	.....	3,807	4,146	2,187	1,749	802	2,209	821	3,391	4,390
July	.....	1,515	1,693	740	395	292	958	403	1,108	1,643
August	.....	612	663	444	324	309	720	261	475	509
September	.....	383	527	263	270	286	454	477	631	319
October	*b* 278	470	844	259	263	289	435	469	1,472	259
November	319	478	374	360	278	236	353	310	665	*a* 816
December	281	*a* 565	*b* 325	*a* 922	*a* 642	288	*a* 1,008	375	*ab* 800	*a, b* 1,300
Mean	292	*a* 1,242	1,403	812	*a* 714	*a* 652	*a* 1,044	*a* 884	1,346	*a* 1,517
Acre-feet, total	.....	900,926	1,014,426	590,219	516,886	471,408	754,931	641,017	945,418	1,094,950

Month.	1899.	1900.	1901.	1902.	1903.	1904.	1905.	Mean.	Mean run-off. *c*		
									Equivalent in acre-feet.	Second-feet per square mile.	Depth in inches.
	Sec.-ft.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*			
January	*a* 1,308	*a* 862	800	381	895	895	895	895	55,031	0.639	0.737
February	*a* 1,113	*a* 1,005	900	412	938	938	938	938	52,094	.670	.698
March	*a* 875	399	500	438	755	755	755	755	46,423	.539	.621
April	617	419	710	638	748	652	760	968	57,600	.691	.771
May	1,378	2,854	2,570	1,169	2,829	1,158	3,411	2,505	154,026	1.79	2.06
June	1,091	2,691	1,782	618	5,189	716	6,090	2,605	155,008	1.86	2.08
July	703	547	594	152	1,655	336	1,091	864	53,125	.617	.711
August	598	231	464	180	526	689	578	474	29,145	.339	.391
September	365	256	446	206	515	692	376	404	24,040	.289	.322
October	492	343	262	242	349	1,449	430	506	31,113	.361	.416
November	490	253	283	249	390	390	390	390	23,206	.279	.311
December	*a* 742	*a* 755	366	547	494	494	494	494	30,375	.353	.407
Mean	814	*a* 884	806	436	1,274	764	1,351	.....	.....	.702	9.525
Acre-feet, total	589,293	641,017	583,271	315,790	920,561	553,019	957,738	.....	711,186	.....	.....

a Probably too high because of ice piling up along the sides of the stream and thus narrowing the channel. It is not likely that the winter flow is ever more than 600 second-feet. The totals are carried out, however, as though the observations gave a correct idea of the discharge.

b Approximate.

c The run-off given is for average months and the totals for an average year as calculated from all observations and estimates.

Discharge of Rio Grande at State Bridge, 1899–1905.

[Drainage area, 7,695 square miles.]

Month.	1899.	1900.	1901.	1902.	1903.	1904.	1905.	Mean.	Equivalent in acre-feet.	Mean run-off.	
										Second-feet per square mile.	Depth in inches
	Sec.-ft.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*			
January	.....	638	594	521	25	306	970	509	31,297	0.066	0.076
February	.....	759	581	758	25	417	1,195	622	34,544	.081	.084
March	.....	583	365	549	34	123	870	421	25,886	.055	.063
April	.....	350	278	315	314	153	744	359	21,362	.047	.052
May	.....	1,430	1,680	490	2,012	21.5	6,494	2,021	124,266	.263	.303
June	.....	1,424	1,032	114	6,375	20.3	8,531	2,916	173,514	.379	.423
July	42	29	82	22	1,178	17.5	258	233	14,327	.030	.035
August	53	22	60	17	47	140	154	70.4	4,329	.0091	.010
September	102	31	50	26	90	196	62.6	79.7	4,743	.010	.011
October	117	37	54	32	64	1,590	98.3	284	17,462	.037	.043
November	259	155	72	30	213	416	216	194	11,544	.025	.028
December	318	571	337	37	302	867	516	421	25,886	.055	.063
Mean	148	502	432	243	890	356	1,676	[a] 678	.....	.071	1.19
Acre-feet, total	54,069	362,304	312,513	173,518	642,607	259,200	1,210,000	.....	489,160	.....	.....

[a] The mean obtained is the mean of the monthly means for the entire period.

Discharge of Rio Grande at Embudo, N. Mex., 1889–1893 and 1895–1903.

[Drainage area, 10,090 square miles.]

Month.	1889.	1890.	1891.	1892.	1893.	1895.	1896.	1897.
	Sec.-ft.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*
January	431	437	586	497	332	475	532	394
February	473	553	616	596	415	503	551	408
March	784	682	917	1,051	501	759	957	561
April	2,261	2,083	2,370	2,979	1,436	2,541	1,797	1,698
May	3,430	4,960	5,965	4,890	3,119	2,679	1,598	5,443
June	2,922	4,107	5,040	3,146	2,533	3,021	367	4,621
July	471	1,593	2,356	538	226	1,335	299	1,274
August	206	814	933	191	230	1,080	249	338
September	212	545	469	152	287	636	228	344
October	283	562	1,681	202	363	494	349	1,538
November	366	616	778	317	330	611	395	1,138
December	542	648	553	324	320	534	414	551
Mean	1,032	1,467	1,855	1,240	841	1,222	645	1,497
Acre-feet, total	747,070	1,064,377	1,348,217	899,730	608,996	885,279	467,960	1,107,818

Month.	1898.	1899.	1900.	1901.	1902.	1903.	Mean.	Equivalent in acre-feet.
	Sec.-ft.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	
January	488	470	508	341	430	317	446	27,423
February	471	481	521	466	462	375	492	27,324
March	695	761	581	518	532	788	720	44,271
April	2,240	1,090	513	628	661	987	1,663	98,955
May	2,149	956	2,323	3,461	798	2,574	3,168	194,793
June	3,480	249	2,814	1,714	440	8,974	3,102	184,582
July	2,566	297	289	398	158	1,506	950	58,413
August	478	236	179	451	246	334	426	26,194
September	338	309	250	359	228	348	336	19,993
October	283	356	248	331	231	323	517	31,789
November	357	535	327	359	231	434	485	28,860
December	339	478	363	423	264	283	431	26,501
Mean	1,157	518	743	787	390	1,437	1,061	.....
Acre-feet, total	838,166	375,138	537,381	572,153	282,032	1,036,600	.....	769,098

Discharge of Conejos River near Los Mogotes, 1899–1905.

[Drainage area, 282 square miles.]

Month.	1899.	1900.	1901.	1902.	1903.	1904.	1905.
	Sec.-ft.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*
March		[a] 144					
April					[b] 436	283	297
May		[c] 1,087			1,291	509	1,544
June		[d] 467			2,323	320	2,226
July					645	76	528
August	[e] 76	[f] 33			173	316	213
September					157	233	87.4
October					138	515	71.5
November	[g] 70						
Mean	73	433					
Acre feet, total							

[a] March 28.
[b] April 17–30.
[c] May 11.
[d] June 23.
[e] August 25.
[f] August 17.
[g] November 28.

RELATION OF SAN LUIS VALLEY IRRIGATION TO THE VOLUME OF THE RIO GRANDE IN NEW MEXICO.

At this point it may not be amiss to call attention to some facts bearing on the interstate relations of irrigation in the San Luis Valley. Agriculture and irrigation spread up the Rio Grande valley from Mexico and Texas, through New Mexico to the San Luis Valley in Colorado. With the rapid expansion of irrigation in the San Luis Valley the water of the Rio Grande was largely withdrawn in Colorado, to the alleged great detriment of agriculture on the lower course of the river. The question of prior rights to the use of the water became a subject for interstate and international discussion. Major Powell in 1890, testifying before the Senate Special Committee on Irrigation and Reclamation of Arid Lands,[a] said:

> Passing into New Mexico, then, the water that practically heads in the high mountains of Colorado is largely, almost wholly, cut off from the Rio Grande, so that no portion of the water that heads in these mountains where there is great precipitation will cross the line into New Mexico (in the dry season) * * *. In a dry season nothing can be raised in the lower region and sometimes dry seasons come two or three together.

Nevertheless, Major Powell argued that it is advantageous that the water in a stream be used for irrigation as near to its source as possible, since there the duty of water is greatest and the loss from evaporation and seepage is least.

> In the valley of the Rio Grande the greater portion of the water during the season of irrigation is lost in the sands, as in the valley of the Arkansas. If the water of the Rio Grande is compelled to flow across the line from Colorado into New Mexico, it will destroy from 1,000,000 to 1,500,000 acres of agriculture above in order to save 200,000 or 300,000 acres in the valley below.

Major Powell urged that the tributaries of the Rio Grande below the Colorado-New Mexico line would, if the water were conserved, fur-

[a] Rept. Special Committee of the U. S. Senate on Irrigation and Reclamation of Arid Lands, vol. 4, pp. 17–33.

nish a sufficient flow to maintain the irrigation of that section as then developed. He pointed out that "when the river emerges into the valley at the foot of Embudo Canyon it is a fine stream and *must always be so whatever water is taken out in Colorado above*" (italics mine). That this somewhat startling and paradoxical statement is borne out by the facts is indicated in the following paragraphs, where the explanation is suggested.

The table on page 20, giving the comparative acreage irrigated from the Rio Grande and its tributaries in 1889 and 1899 shows, an increase in that period of over 100 per cent, yet the discharge of the Rio Grande at Embudo (table, p. 14) shows no corresponding systematic diminution during the irrigation months, notwithstanding that the water is almost wholly removed from the river in its course through the valley, as shown by the gage at State Bridge. The following table of the comparative discharge at Del Norte, State Bridge, and Embudo for 1900 to 1903, inclusive, the period for which we have data from all three points, brings out the fact clearly:

Comparative discharge, in second-feet, of the Rio Grande at Del Norte, State Bridge, and Embudo, 1900–1903.

	1900.			1901.		
	Del Norte.	State Bridge.	Embudo.	Del Norte.	State Bridge.	Embudo.
January	862	638	508	800	594	341
February	1,005	759	521	900	581	466
March	399	583	581	500	365	518
April	419	350	513	710	278	628
May	2,854	1,430	2,323	2,570	1,680	3,461
June	2,961	1,424	2,814	1,782	1,032	1,714
July	547	29	289	594	82	398
August	231	22	179	464	60	451
September	256	31	250	446	50	359
October	343	31	248	262	54	331
November	253	155	327	283	72	359
December	755	571	363	366	337	423
Total acre-feet	641,017	362,304	537,381	583,271	312,518	572,153

	1902.			1903.		
	Del Norte.	State Bridge.	Embudo.	Del Norte.	State Bridge.	Embudo.
January	381	521	430	.....	25	317
February	412	758	462	.....	25	375
March	438	549	532	.....	34	788
April	638	315	661	748	314	987
May	1,169	490	790	2,829	2,012	2,574
June	618	114	440	5,189	6,375	8,974
July	152	22	158	1,655	1,178	1,506
August	180	17	246	526	47	334
September	206	26	228	515	90	348
October	242	32	231	349	64	323
November	249	30	231	.....	213	434
December	547	37	264	.....	302	283
Total acre-feet	315,790	173,518	282,032	920,561	642,607	1,036,600

Comparison of the measurements at Del Norte with those at Embudo for the whole period from 1890 to 1903, inclusive, shows further that the river as it is discharged from the canyon is very nearly of the size that it is at Del Norte. That is to say, during the season of low water there is added to the river in the course of its passage through the canyon a volume nearly equal to that of the river at Del Norte. Examination of the topography of the country shows that no tributaries of any consequence come into the canyon from the west and from the east, but six small creeks flow into it, namely, Costillo, Colorado, San Cristobal, Los Montes, and Pueblo creeks and Arroyo Hondo. These are all short, with high gradients, and head in the range just east. Even in flood they carry no such volume of water as the Rio Grande at low stage; but the season alluded to was that of low water, and during such times all the water in these creeks is practically exhausted in irrigating the bottoms adjacent to them. The increment to the river in the Embudo Canyon must be explained in some other way. A. L. Fellows, formerly United States hydrographer in charge of work in Colorado and New Mexico, has noted the occurrence of large springs in the canyon above Embudo station and has suggested that the San Luis artesian basin finds an outlet in this way. No description of these springs is extant, and their location, size, and number are unknown. The strata which go to make up the Conejos Mountains and the San Luis Hills form an alternating series of gravel beds and lava flows, as will be shown more in detail on a later page. At the south rim of the valley, where the water-bearing beds of the valley abut against the San Luis Hills, a great many springs come up along the contact, among them the McIntire Springs (Pl. XIII, *B*) with a flow of over 20 cubic feet per second. It is reasonable to suppose that other water-bearing beds in contact with the interstratified gravel beds of the older formation will communicate their water to those gravel beds and that the Rio Grande itself may do likewise, and that this water may be poured into the canyon at different points above Embudo. The increment thus gained is apparently not less than 150 second-feet and possibly is considerably more, the exact amount being difficult to determine owing to irregularities in the record. For instance, in the winter months the record occasionally shows more water at State Bridge than at Embudo, which naturally seems impossible, there being no known source of loss between the two stations. The error probably arises from encroaching shore ice, which causes too high gage readings at State Bridge, where the channel is narrow.

Experiments have shown that the movement of water underground in sand and gravel beds is very slow, usually 1 or 2 miles per annum, certainly not over 3 in the extreme case. This being so, it follows

that the supply from springs in the canyon, if derived from the aquifers in the San Luis basin, is practically constant, since the amount delivered in any period of time is not dependent upon the rainfall during the same period, because the water rising in the springs has been percolating slowly underground for many years before it reaches the surface. Further, the principal intake of the artesian system on the Rio Grande is well toward the edge of the valley, between Del Norte and Monte Vista, above the head-gates of all but one of the main canals, and as this canal has a later priority than one below the catchment area, it follows that the artesian basin has the first call upon the flow of the Rio Grande and of the other streams as well. That this supply is exacted is shown by the fact that there is no annual variation in the head of the wells which just reach the surface along the margin of the area of flowing wells. These facts bear out Powell in the statement quoted at the beginning of this discussion that the flow of the Rio Grande below the Embudo Canyon will always be largely independent of the flow at the head of the canyon. Thus the sands and gravels of the San Luis Valley act as a natural reservoir with lasting benefit to the Rio Grande valley below.

RESERVOIR SITES.

The great excess of water wasted during the flood season and the frequent lack of water when needed have turned attention to the possibility of reservoirs in the upper courses of the streams to conserve the flood water and have led to search for available sites. Naturally those first sought are the ones requiring the least expenditure of money to make them available. The head branches of most of the larger streams emptying into the valley held glaciers of various size during past ages, and many of the morainic dams and terraces resulting from glacial action offer tempting sites for storage reservoirs. Such formations require most careful testing, because from the nature of their material they will not, as a general rule, hold water after it has accumulated in volume sufficient to cause much pressure. But doubtless there are numerous sites in the various streams that will serve admirably. Such are reported on Alamosa Creek and in the upper course of the Rio Grande. One of those on the Rio Grande has been thoroughly tested by the company operating the Rio Grande and Monte Vista canals, and a reservoir is now under construction.

The high gradient and the small drainage areas of the streams coming down from the Sangre de Cristo Range preclude the establishment there of any but small irrigation systems. On the other hand, the low gradient and larger drainage areas of the streams entering from the west side of the valley are very advantageous to large systems. Toward their headwaters these streams branch out and their

valleys take on the rolling character of glaciated cirques and are heavily covered with pine and spruce, as shown in the typical view of upper Rock Creek (Pl. II, *B*). The timber, by checking the run-off in time of heavy rains and by protecting the snow from rapid melting, controls the discharge of the streams and to that extent does away with the necessity for storage reservoirs.

In accordance with a recommendation of the United States and Mexican International Boundary Commission in 1896, the Secretary of State requested the Secretary of the Interior to withdraw from entry all reservoir sites in the Rio Grande drainage area and to suspend action on all applications for rights of way for canals through public lands. Such action was accordingly taken December 5, 1896. Recently, upon the suggestion of the United States Reclamation Service, this order has been suspended in so far as it relates to bona fide applications made under the state law prior to March, 1903, when the Reclamation Service took up the Rio Grande project. From that date, of course, the project has the priority. The proposed reservoir at Engle, N. Mex., will have a storage capacity of 2,000,000 acre-feet, irrigating 180,000 acres, and will be capable of storing all the flood waters of the Rio Grande from year to year.

IRRIGATION.

Canals.—The full flows of all the streams entering the valley are appropriated for purposes of irrigation. The Rio Grande is the main source of supply. The following table shows the total appropriations and dates of the main priorities of the principal canals and ditches taking water from that stream, as decreed by the courts in 1900:

Water appropriated for principal ditches and canals from the Rio Grande, and total decreed appropriation.

Priority.	Canal.	Appropriation.
		Cubic feet.
1874 and 1879	Centennial ditch	82.4
1881 and 1891	Rio Grande (Del Norte) canal	905.6
1882 and 1889	Monte Vista (Citizens') canal	257.8
1882 and 1890	Empire canal	667.5
1885	San Luis Valley canal	92.9
1886	Costilla ditch	103.3
1887	Prairie ditch	105.1
1887	Farmers' Union canal	138.8
	Total for principal ditches and canals	2,353.4
	Total appropriation decreed by court to 1900	3,022.59

The foregoing table, when compared with the table giving the average monthly flow of the Rio Grande from April to September, inclusive, for sixteen years (p. 20), shows that the waters of this stream are greatly overappropriated, even in the flood season.

Average monthly discharge of the Rio Grande at Del Norte, 1890–1905.

	Second-feet.
April	968
May	2,505
June	2,605
July	864
August	474
September	404

Acres irrigated from the Rio Grande and tributaries.[a]

County.	1899.	1889.	Per cent increase.
Hinsdale	1,339	1,389	.....
Mineral	.....	2,640	.....
Saguache	75,909	52,453	44.7
Rio Grande	71,325	21,797	227.2
Costilla	50,290	25,918	94.0
Conejos	98,486	46,273	112.8
	299,989	147,830	102.9

[a] Census Bulletin 177, 1902, p. 14.

This acreage is confined to the San Luis Valley, except perhaps 10,000 acres lying on the upper courses of the river or its tributaries.

The total area of the irrigated land in same region for 1902 is given by the Bureau of the Census[a] as 303,985 acres. This shows no material increase over 1899. Later figures are not available.

Pumping the "sub."—Between Mosca and Hooper is a region in which the supply of ditch water for several years has been inadequate, and here was developed the scheme of installing a gasoline pumping plant and pumping from the underground water level as raised and maintained by subirrigation. No change in the application of the water thus gained was proposed. It was to be used in subirrigating; that is, the level of underground water was to be raised by adding to it water taken from it—another statement of the problem of raising one's self by one's boot straps. The application of the water might be changed by the substitution of surface irrigation for subirrigation methods, thus doing away with the necessity of keeping up the underground water level; but a difficulty appears in that case. The interesting question is raised as to the right of one person to lower the water level when his neighbors, in the customary practice of irrigation, are under the necessity of keeping it up.

Pumping the underflow.—Many of the smaller streams on either side of the valley run out into the valley during the flood season but during the remainder of the year, except for short intervals, disappear beneath the gravel, where they emerge from the mountains at the upper edge of the alluvial slope. But by digging down a few feet in

[a] Bulletin 16, Irrigation in the United States: 1902, p. 55.

the rocky channels of such streams a persistent and heavy underflow is encountered. It is possible by installing a gasoline pumping outfit to raise this underflow and irrigate successfully when the water is not running in the streams. One such pumping outfit has been in successful operation in 1903 and 1904 by Mr. K. Eilinghoff 2 miles east of Chamberlain Hot Springs. The equipment consisted of a 3½-horsepower gasoline engine and a 2-inch centrifugal pump with a normal discharge of 125 gallons per minute. The water was taken from a well 16 feet deep, in which the water stood within 7 feet of the surface but with steady pumping sank to 11 feet from the surface, where it remained.

The cost of installing such an outfit is not large, and the cost of operation for the short time it would ordinarily be in use, at critical periods in the growth of the crop, will also be small, so that there seems to be a genuine need for such plants, particularly in the northern portion of

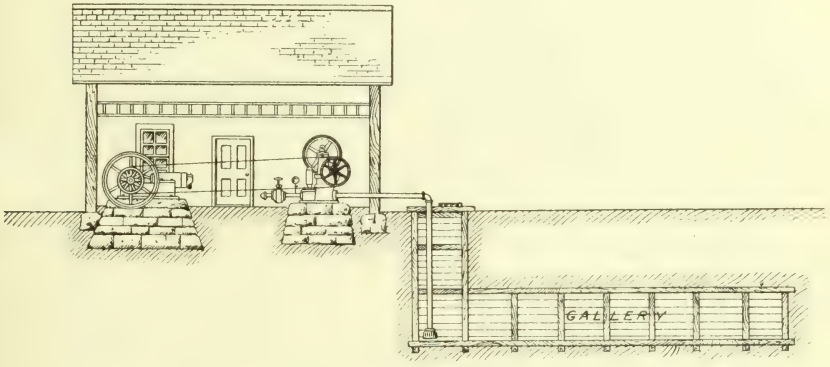


FIGURE 2.—Plan of pumping plant, showing subterranean gallery.

the valley and wherever else the supply of ditch water is short and the underflow sufficient.

Where the underflow may not be adequate with a simple well, a subterranean gallery will be found more efficacious. The accompanying plan (fig. 2) of the city pumping plant of Castle Rock, Colo., may be advantageously copied in designing outfits of this sort.

Canvas flumes.—Along the west slope of the Sangre de Cristo Range many streams afford water that is sufficient to irrigate small tracts but in the irrigation season is entirely lost in passing over the alluvial slope at the foot of the range. A plan adopted by the placer miners of Alaska, and used in irrigation in California, might possibly be worked here to advantage. At some places in Alaska water is carried on the surface of the ground for miles in a flume made by sewing together the two sides of a strip of cotton duck canvas, making a long canvas pipe. Or the bottom of a ditch may be lined with such canvas.

The cloth will be less subject to damage by cattle and rodents, however, when sewed up in the form of a hollow cylinder and filled with water. Such a flume might conceivably last for several irrigation seasons of a couple of months each. A subsurface dam across the canyon near its discharge upon the alluvial slope would help by bringing all the underflow of the stream to the surface at the intake of the flume.

CLIMATE.

The most prominent feature of the climate of the San Luis Valley is the prevalence of sunshine. Records are not at hand to show this fact with exactness, but, except for short intervals each day during the brief summer showery season and other rare occasions, sunshine prevails throughout the year. Taken in conjunction with the dry, rarefied atmosphere at this altitude, which allows a large amount of the sun's heat to reach the earth's surface and permits rapid radiation therefrom, this sunniness acts to relieve the worst extremes of daytime temperature. On the hottest days it is cool in the shade, and on the very coldest days it is comfortable in the sunshine.

The most disagreeable feature of the climate is the southwest wind, which occasionally blows steadily for several days at a time, picking up the sand and driving it onward with the force of a sand blast.

The following tables of temperature and precipitation are based upon observations at each of the towns named for the period indicated. The value of such observations is strictly in proportion to the interval of time that they cover. The records which are thus of greatest value are those taken at San Luis, Saguache, Garnett, and especially the temperature records at Fort Garland, though those from Monte Vista and Wagon Wheel Gap are also complete enough to be of interest. The data included in these tables were furnished by the United States Weather Bureau, and, except the Fort Garland observations, through Mr. F. H. Brandenburg, district forecaster at Denver, Colo. The temperatures in the tables, as elsewhere in this report, are expressed in degrees Fahrenheit.

The observations at Fort Garland, covering a period of thirty years, with a short interruption in 1864–1866 and entirely antedating the other observations in the valley, are of especial interest because of their length and the opportunity they afford for comparison. For the period 1852–1858, inclusive, the observations were made at Fort Massachusetts, in the valley of Ute Creek, a short distance above the present site of Fort Garland, where the military post was removed in 1858.

Average monthly temperature at stations in San Luis Valley.

[Degrees Fahrenheit.]

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Term of record.
Saguache	18.3	23.6	33.6	43.4	51.6	63.8	64.4	62.7	55.7	45.4	33.0	20.	1886–1905
Garnett	13.5	21.7	31.2	41.6	49.2	57.8	61.3	60.6	53.6	41.4	30.0	13.4	1897–1905
Monte Vista	16.1	20.8	32.3	41.6	51.8	59.1	63.5	62.5	55.2	43.8	29.7	17.9	1886–1896
La Jara	22.1	22.3	34.8	45.0	52.3	60.8	64.2	63.7	58.5	47.6	35.2	25.0	1892–1897
Conejos	18.1	26.2	35.5	41.8	49.4	58.0	62.5	62.6	58.8	45.3	36.2	18.6	1904–1905
San Luis	19.5	24.2	33.3	42.3	50.5	58.6	63.1	62.4	55.8	45.3	34.0	22.5	1891–1905
Fort Garland	18.2	22.8	33.5	41.3	52.0	62.0	66.2	63.7	55.2	44.1	30.0	21.2	1852–1883
Average	18.0	22.9	33.2	42.1	51.3	60.8	64.3	62.8	55.5	44.6	31.6	20.	
Wagon Wheel Gap	12.9	17.6	26.8	35.4	42.2	50.4	54.5	54.7	47.9	38.3	27.1	12.7	1898–1905

The extremes of temperature for summer and winter at Saguache, Garnett, and San Luis are included in the next table. The lowest figure recorded is 40° below zero at Garnett in December and the highest figure is 98° at San Luis in August. The observations at Garnett are the most typical of the valley, as the station lies in the full sweep of the valley winds, while Saguache and San Luis are protected by the adjacent foothills. The monthly mean temperatures for the winter months at Garnett range from 1° to 10° lower than at Saguache and San Luis, and the range of the extremes is still greater.

Maximum and minimum temperatures at Saguache, Garnett, and San Luis.

[Degrees Fahrenheit.]

Month.	Average.	Highest.	Lowest.
Saguache:			
December	21	63	−36
January	18	59	−23
February	23	64	−13
June	60	92	28
July	65	97	31
August	63	94	35
Garnett:			
December	13	55	−40
January	13	52	−30
February	22	64	−33
June	58	89	20
July	61	88	29
August	61	92	30
San Luis:			
December	22	58	−30
January	20	57	−30
February	24	63	−34
June	59	96	23
July	64	95	30
August	63	98	32

The next table gives the average monthly precipitation at various points in the valley calculated from all available records. The figures for the precipitation at Fort Garland and Wagon Wheel Gap are added for the sake of comparison, though they have been excluded in making up the average for the valley, the former for reasons given later and the latter because the station is not within the valley proper. From the valley average it will be seen that July has the greatest precipitation, with occasional showers in August and September.

Average monthly precipitation at stations in San Luis Valley.

[Inches.]

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Term of record.
Saguache	0.26	0.35	0.21	0.62	0.89	1.10	1.80	1.80	0.86	0.70	0.28	0.23	1886–1905
Garnett	.08	.24	.23	.25	.72	.59	1.23	1.35	.84	.40	.25	.25	1891–1905
Monte Vista	.24	.51	.32	.85	.81	.29	1.58	1.28	.87	.48	.22	.32	1886–1896
La Jara	.11	.91	.13	.15	1.00	.22	1.13	1.04	.64	.69	.30	.03	1892–1896
Conejos	.78	.67	.20	.00	.06	1.00	.94	1.46	3.53	.99	.00	.47	1904–1905
San Luis	.49	.64	.89	.95	1.23	.67	2.26	1.27	1.18	.92	.36	.79	1891–1905
Average for valley	.29	.48	.42	.62	.91	.65	1.66	1.19	.97	.66	.28	.40	
Fort Garland	.18	.82	.40	.72	.90	.72	1.93	1.78	1.31	.54	1.10	.87	1852–1874
Wagon Wheel Gap	.45	.64	.90	.99	1.03	.59	1.53	2.19	1.42	1.09	.68	.41	1898–1905

The next table gives the yearly precipitation for each point in the valley and the average for the valley itself for 1887–1905, inclusive, so far as there are records, except for Fort Garland. The record of Wagon Wheel Gap is added, as of interest from its position in the upper drainage basin of the Rio Grande. The mean annual precipitation for the valley is 8.33 inches. The maximum annual precipitation is 18.85 inches, recorded at San Luis in 1891, and the minimum is 2.88 inches, given for Saguache in 1896. San Luis and Wagon Wheel Gap have the highest average annual precipitation, as is to be expected from their geographic position. The precipitation on the mountains about the valley, and especially high up in the Sangre de Cristo and Culebra ranges east of the valley, is doubtless much greater than in the valley, owing to the fact that the southwest moisture-laden winds are forced to ascend to colder altitudes in crossing over those ranges, with local precipitation as a result.

Average annual precipitation at stations in San Luis Valley.

[Inches.]

	1887.	1888.	1889.	1890.	1891.	1892.	1893.	1894.	1895.	1896.
Saguache	10.69	4.41	7.05	.....	.....	.....	.....	.....	14.01	2.88
Garnett	.....	.....	.....	.....	.....	4.87	4.46	6.33	10.37	3.50
Monte Vista	8.48	6.21	5.01	6.48	9.17	7.47	6.84	6.22	9.12	.....
La Jara	.....	.....	.....	.....	.....	.....	7.15	6.75	9.44	.....
Conejos	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
San Luis	.....	.....	.....	.....	18.85	11.04	10.87	10.58	15.76	12.31
Average for valley	9.59	5.31	6.03	6.48	14.01	7.79	7.33	7.47	11.74	6.23

	1897.	1898.	1899.	1900.	1901.	1902.	1903.	1904.	1905.	Average.
Saguache	8.84	8.06	5.96	6.25	6.86	7.09	6.51	7.26	3.76	7.12
Garnett	6.25	4.60	6.96	.....	.....	8.18	5.18	9.51	7.08	6.44
Monte Vista	.....	.....	.....	.....	.....	.....	.....	.....	.....	7.22
La Jara	.....	.....	.....	.....	.....	.....	.....	.....	.....	7.78
Conejos	.....	.....	.....	.....	.....	.....	.....	9.86	.....	9.86
San Luis	13.93	14.20	10.04	10.16	13.02	7.45	6.98	9.56	10.14	12.71
Average for valley	9.67	8.95	7.65	8.21	9.94	7.57	6.22	9.05	7.00	8.22
Wagon Wheel Gap	.....	12.26	12.25	7.83	9.73	10.28	.....	14.50	.....	12.81

As explained with regard to the table of average monthly temperatures, the table of precipitation that follows combines the observations at Fort Massachusetts and Fort Garland. The figures for 1870–1872, inclusive, are regarded by the United States Weather Bureau as very questionable, and they have accordingly been excluded in making the averages. Aside from these years the table appears to be fairly reliable, and is of much interest for purposes of comparison.

Precipitation at Fort Garland, 1852–1863 and 1866–1874.

[Inches. Blanks indicate incomplete records.]

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1852										1.84	6.34	1.45	9.63
1853	0.22	0.76	0.94	0.39	1.49	1.11	3.04	1.48	1.25				10.68
1854					3.93	.24	2.14	2.61	1.53	.35		2.30	13.10
1855	.00	.67	1.47	.41	.98	.86	2.60		3.33	.00	5.27	.38	15.97
1856	.15	2.14	.35	1.35	.00	.55	2.19	3.30	1.55	.95	.79	.55	13.87
1857	.80	.52	.20	1.51	.75	.95	.72	3.98	1.34	1.19	2.03	.67	14.66
1858	.54	.20	.08	2.11	1.00	.58	1.36			1.22	.68	.15	7.92
1859	.00	.15	.27	.19	.32	1.32	2.72	4.75	.68	.55	.20	.20	11.35
1860	.20	.08	.53	.33	.00	.72	2.61	.77	.85	.25	.24	.04	6.62
1861	.03	.04	.87	.25	1.01	1.07	.74	.30	.93	.13	.06	.01	5.44
1862	.24	.02	.16	.40	.24	.41	1.26	1.46	1.78	.00	.22	.14	6.33
1863		.84	.06	.00	.22	1.07	.07	.02	.03	.13	.21	.24	2.89
1866									.79	.35	.08	.13	1.35
1867	.06	.15	.12	.89	.21	.01	.36	.29	.26	.02			2.37
1868	.16		.12			.01	7.19	3.26	1.80	.42	.03	4.01	17.00
1869	.65	.90	.28	.36	2.30	.77	1.28	1.03	2.55	.16	.14	3.00	13.42
1870[a]	.65	1.05	.85	7.57	.60	6.65	7.30	7.50	.90	1.30	.15	3.35	37.87
1871[a]	1.20	1.45	2.80	2.45	1.45	.25	1.00	1.25	2.90	1.40	7.10	1.75	25.00
1872[a]	2.25	2.75	3.65	2.78	6.25	7.75	10.30	5.68	.83	.10	.00	.00	42.34
1873	.00	2.25	.00	1.75	.00	1.58	.80	.48	.18	.50	.01	.20	7.75
1874	.50	2.80	.50	.15	.08	.20	1.72	1.12	2.05	1.23	.25	.50	11.10
Average	.18	.82	.40	.72	.90	.72	1.93	1.78	1.31	.54	1.10	.87	[b] 11.27

[a] Record unreliable.
[b] Average annual precipitation excluding 1870–1872, inclusive.

AGRICULTURE.

ORDER OF SETTLEMENT.

The first population of the San Luis Valley was Mexican, and the little Mexican "plazas" are scattered along both sides of the valley but are more numerous in its southern part. The Mexicans constructed no large irrigation ditches, and their settlements were perforce limited to the mountain valleys, to the border of the San Luis Valley, and to the immediate banks of the perennial streams in the valley.

Following the advent of Americans came colonization schemes and the construction of larger canals, permitting the central part of the valley to be settled. North of the Rio Grande the country adjacent to the railway, irrigated by the Farmers' Union, Prairie Ditch, and San Luis canals, was first settled in preference to the more gravelly soil to the west. Gradually, however, the gravelly land was found to be fertile and suited to cultivation as well as the other, and the cultivated territory spread farther westward. Then, from a combination of causes, the land that lay to the east along the railway and was the first to be cultivated was practically abandoned. These causes were

(1) exhaustion of the soil by continuous cropping without rotation; (2) exhaustion of the water in the canals by farms nearer the heads of the canals; (3) failure of the canals in years of drought through lateness of their priorities; (4) injurious accumulation of alkali in the soil. This accumulation of alkali is due to the prevailing practice of subirrigation. The alkali is largely of local origin, a result of the concentration at the surface of the salts in the soil of the affected region itself, but is also partly derived from the soil of the contiguous and higher regions to the west and carried by seepage water to the lower land, there coming to the surface and being precipitated.

Remnants of the population brought in by colonization schemes exist in different parts of the valley, as, for instance, settlements of French Canadians about Carnero, of Scandinavians at Swede Corners south of Saguache and in the neighborhood of Swede Schoolhouse southwest of Alamosa, and of Mormons at Manassa, Sanford, Richfield, Freedom, and, until recently, at Zapato.

NATIVE VEGETATION.

The native vegetation of the valley varies with the region and the ecologic conditions. On the high mountain sides pine, aspen, and spruce, lower down piñon and cedar, and in the valleys and along streams cottonwood and willow constitute the forest growth. The valley bottom away from streams is covered with a growth of "chico" and "greasewood," the former predominating in adobe soils and both growing in the loams. Sagebrush does not grow in the valley bottom but is found in the foothills in places. Wild currants and raspberries thrive abundantly, growing well up the mountain slopes. Of the currants three varieties are found, black, red, and yellow.

Much native hay is grown along the bottoms of the streams that come down into the valley from either side. These vegas, or native meadows, were among the first tracts taken up as homesteads, and on account of their value and the ease of cropping are not plowed up to be planted in other crops unless they run out. The market for hay is largely local, yet some is shipped.

CULTIVATED CROPS.

The principal crops are wheat, oats, wild hay, alfalfa, potatoes, peas, and barley. Wheat was the first crop and is the most important crop to-day. Very little trouble was taken in planting wheat by the early settlers. The brush was uprooted by dragging a heavy railroad rail across the land, raked up into windrows and burned, and the wheat drilled in directly without plowing. Such methods sufficed to get large yields and led to the planting of large acreage and the building of mills and elevators at Del Norte, Monte Vista, Hooper,

Mosca, Alamosa, La Jara, and Conejos. In time the heavy wheat returns failed and crops were rotated, or the fields were planted in alternate years, lying fallow in the intervals.

In the last few years, however, a new industry has sprung up, which yields good returns and which, in the long run, will be more valuable, in that it will restore the land to its pristine fertility. This is the business of fattening young lambs for the spring markets. Quarter sections are grown with peas, or a mixture of peas and oats, and the lambs are pastured on these, thus at one stroke doing away with the need of harvesting the crop and hauling it to market, besides resting the land by raising a leguminaceous crop and returning nearly all the mineral plant food to the soil. The practice promises to spread rapidly and will unquestionably make for the good of the valley. The meat of lambs fed on peas is said to be much improved in flavor and at all times commands the best prices.

The late and short growing season in the valley of necessity cuts out some fruits and crops. Early corn will in a favorable year make small roasting ears. Apples and pears have been grown in protected places, but these are unimportant and fruit is mostly imported from the outside.

METHODS OF IRRIGATION.

In the San Luis Valley the method of irrigation practiced almost universally is a modification of subsurface irrigation, locally known as "subirrigation." In subsurface irrigation the water is carried in underground tile or perforated pipe directly beneath the roots of the plant to be irrigated, as, for instance, beneath a row of fruit trees. In subirrigation, as practiced in the valley, the water is conducted onto the field in trenches at such distances apart as experience and the character of the soil shall determine. These trenches are closed at the lower ends and water is supplied to them only so fast as it is taken up by the sides and bottom of the trenches, care being taken to prevent overflowing. The loamy character of the soil allows it to absorb the water rapidly, while the level character of the surface permits the raising of the level of ground water to a height within reach of the rootlets of the growing crops. The object in view is to keep the level of the underground water at this height. If the spring rains have not left the water level near the surface, it may be brought so by a preliminary flooding.

This method requires much less care and trouble than the method of flooding or surface irrigation, and is as efficacious as that method, though it requires much more water. Its long-continued practice, however, brings a result that is detrimental; that is to say, it renders the soil alkaline. In countries of greater rainfall, where irrigation is not needed, the constant flooding of the soil since its formation as a result

of heavy rains and the consequent run-off has leached from it much if not all of its content of injurious salts, as well as much of the mineral matter needed as plant food. For the same reason, in the so-called arid regions, correlated with the liability to become alkaline under careless irrigation is the greater fertility of the land due to the greater abundance of mineral plant food.

The salts which render soil alkaline are, in the order of their injurious effects, sodium carbonate ("black alkali"), sodium sulphate ("Glauber's salt"), and sodium chloride (common salt). These are originally so widely scattered in small particles through the soil and subsoil as not to be injurious. They are very readily dissolved in the water put on in subirrigation, which penetrates both the soil and the subsoil. As this water is drawn to the surface and evaporated, it leaves these salts behind it on the surface of the ground. As a result of this continuous process, the salts are leached from the soil and subsoil and accumulate on the surface of the soil, rendering it in time unfit for tilling. Once in solution, the only way the salts are redeposited in the soil is by evaporation. The remedy is of course to reverse the process of irrigation; that is to say, to apply the water at the surface, preferably by flooding, and to withdraw it from below by drainage, thus continually carrying away the salts in solution and lessening their amount in the soil. This method, as just pointed out, has the disadvantage of removing from the soil some of its valuable elements.

Not all of the water comes immediately to the surface to be evaporated, especially on the less gently sloping gravelly land of the alluvial-fan formations to the west. A portion of the water continues down the slope as underflowing ground water until forced to the surface by clay beds beneath. Here it issues as a "seep," usually making an "alkali spot."

The alkali map accompanying the report on the soil survey of the San Luis Valley,[a] to which the reader is referred for further details, shows that in the region surveyed the most alkaline territory lies in a semicircle about the foot of the steeper part of the great Rio Grande alluvial fan. The author of the report says that "the subformation is such that the ground water is naturally near the surface in this territory." In other words, this is the region where the superficial gravelly and sandy covering of the fan thins out and the clay beds of the Alamosa formation approach the surface.

How short-sighted was the man who congratulated himself because his land required no irrigation when his next neighbor's land above was thoroughly saturated or "subbed." He simply was slowly accumulating a large part of his neighbor's alkali. Perhaps his

[a] U. S. Dept. Agr., Field operations of the Bureau of Soils, 1903, pp. 1099–1119.

neighbor in turn was having alkali unloaded upon his land. But the man for whom there is no escaping the alkali under the system of subirrigation is the one on whose place the seep rises to the surface. As noted before, the remedy lies in surface application of the water, with subsurface drainage, not only greatly lessening the needful amount and making the supply irrigate a larger territory, but carrying away the alkali.

The report referred to above, based on careful study of the valley, concludes that the amount of alkali in the valley is nowhere so great as to preclude successful reclamation by proper methods.

GEOLOGY.

INTRODUCTORY STATEMENT.

Popularly the San Luis Valley or park is supposed to be the southernmost one of a chain of four great parks, of which North, Middle, and South parks are the others; in reality, it differs genetically and geologically from that series, which, with its southern continuation, Wet Mountain Valley and Huerfano Park, occupies a depression between the Front Range and Wet Mountain axis and the Mosquito Range and Sangre de Cristo axis, whereas the San Luis Valley occupies a depression west of the latter axis and between it and the Sawatch Mountains. Furthermore, the former depression began to take shape much earlier—as far back as the Triassic at least—and has been subject to sedimentation more or less continuously from that time until the Pleistocene, whereas the San Luis Valley shows no formations older than Miocene, and is for the most part occupied by Tertiary or early Quaternary sediments.

For purposes of geologic description the valley and its environment divides itself naturally into four parts—the west ranges, the east ranges, the San Luis Hills, and the valley proper.

THE WEST RANGES.

The western mountains, the Sawatch and Conejos ranges, are made up, on their eastern flanks adjacent to the San Luis Valley, of alternations of gravel beds, andesitic flows, and rhyolitic tuffs cut through in places by dikes and the volcanic necks of centers of effusion. These flows incline toward the valley with dips varying from 6° to 15°, and extend under it, being penetrated in some of the wells at the south end of the valley. In Plate III, *A*, the lava-capped mesa that stretches eastward from Los Mogotes Peak and is cut through by the canyon of Conejos River is seen gradually to approach and merge with the floor of the valley.

ALAMOSA CREEK VALLEY.

Alamosa Creek leaves the foothills about 6 miles west of Capulin, through a defile in the lava rim. The south side of the defile rises into a bluff a hundred feet high, which is shown in Plate III, *B*. This bluff, capped with pyroxenite-andesite[a] 40 feet in maximum thickness, dips 8° to 10° E. The lower part is massive and lies upon a water-sorted conglomerate, at the contact with which the lava is much broken. Bowlders from the conglomerate seem to be drawn up into the lava, and it is penetrated by crevices and "chimneys" of loose-textured rock, apparently the result of steam escaping when the flow covered the conglomerate. The conglomerate has a burnt, reddish color, and the sandy matrix is more or less consolidated and indurated. These gravel beds rise upstream and 300 yards west come to the top of the bluff, where they are interbedded with and underlain by brecciated pumice or rhyolitic tuffs. Farther west these in their turn are underlain by other gravel beds, which become more arkose toward the bottom, where they rest on pinkish mica andesite. In each of the conglomerate beds, mingled with the waterworn bowlders, there are numerous subangular bowlders, some of which are rudely facetted and in outline strongly resemble glaciated bowlders. Though none was seen which exhibited striæ or glacial scratches, yet the field observations left the writer convinced that a period of local glaciation antedated the last lava flow in this vicinity. If this glaciation occurred in the headwaters of Alamosa Creek, the carrying of the bowlders by the stream to their present site would have worn away the superficial glacial striæ and left them in the condition in which they are now found.

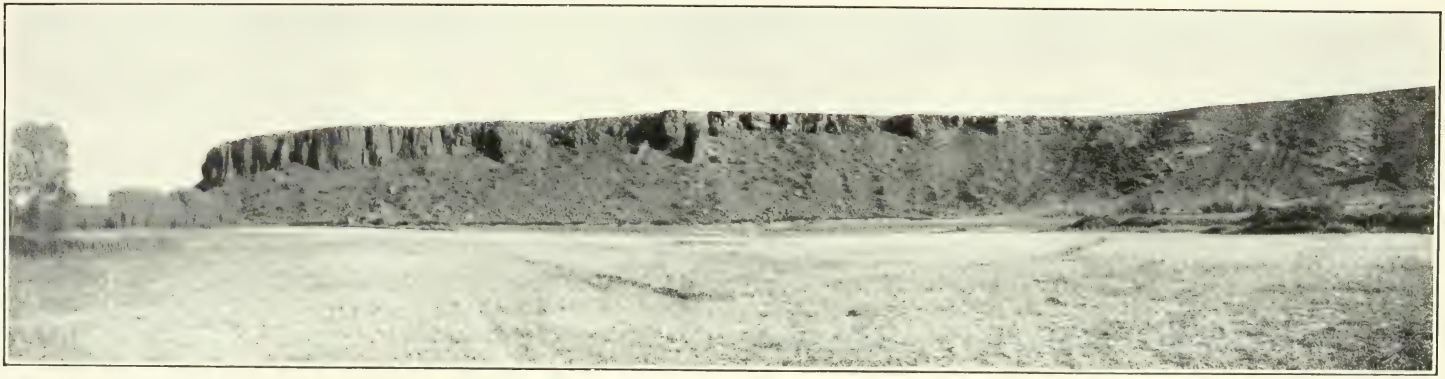
The ledge of pink mica andesite varies from about 30 to more than 70 feet in thickness and is the most persistent and characteristic bed of the eastern border of the west ranges. It furnishes the stone which has been most widely used for building purposes in the valley. It can be quarried in blocks of any desired size, works easily when freshly quarried, hardens on exposure, and has in general a pleasing creamy tint, though varying somewhat in shade in different outcrops. Many public buildings, as well as business blocks and residences, in Antonito, Conejos, La Jara, Manassa, Alamosa, and Monte Vista are constructed of this stone.

Below the pink mica andesite are successive beds of andesite and rhyolitic tuffs and vitrophyres. The following is a section of the various beds from the uppermost sheet of pyroxenite-andesite downward to the pink mica andesite:

[a] The various igneous rocks noted herein have been determined by Whitman Cross, of the United States Geological Survey.

A. VIEW OF LAVA-CAPPED SLOPE DIPPING BENEATH THE VALLEY WEST OF ANTONITO.

Showing characteristic appearance of the Conejos River alluvial fan.



B. BLUFF OF SANTA FE FORMATION ON ALAMOSA CREEK.

Section of south side of Alamosa Creek canyon, near the lower end.

	Feet.
Pyroxene andesite; irregular contact at base	40
Bowlders in sand matrix	12
Bedded sand	1
Bowlders in sand matrix	12
Bowlders in brecciated pumice tuff	3
Bowlders with indurated sand matrix	1
Bowlders and sand; irregular contact at base	2
Pumice breccia with small waterworn pebbles	2
Sand and bowlders of various shapes—angular, subangular, and waterworn	4
Pumice breccia	14
Concealed, probably gravel	8
Brecciated pumice with rounded quartz and felsite pebbles $\frac{1}{8}$ inch in diameter. Upper portion conglomeratic with bowlders of various rocks	12
Pumice	8
Apparently pumice	80–100
Bedded gravel and sand becoming lighter in color and arkose toward the bottom	50
Pinkish mica andesite	40±

CAT CREEK VALLEY.

The canyon of Cat Creek at the point where it debouches upon the plain is not deep. At the quarry, about a mile up the canyon, the mica andesite first appears, continuing to the forks of the canyon at Tiptons, forming the walls of the south canyon to a point 3 miles beyond, and showing in the walls of the north canyon to the vicinity of Wood's cabin, where the road leaves the canyon and goes up the steep hill. From this it will be seen that the eastward dip of the mica andesite here does not exceed the drainage gradient of Cat Creek, which is a considerably lower dip than the same rock shows in Alamosa Creek.

ROCK CREEK VALLEY.

In Plate IV, *A*, is shown Painted Rock Bluff along the north bank of Piedra Pintada (Painted Rock) Creek, locally called Rock Creek, which takes its name from the fact that for about a quarter of a mile in the middle of the bluff shown in the photograph the face of the soft andesite bluff is covered with Indian picture writing. The andesite ledge rises westward for a mile and a half to the forks of Rock Creek, where it shows a face of 60 or 80 feet of the pinkish mica andesite, the thickest exposure noted.

These beds of pinkish mica andesite, which appear in the canyons of Alamosa Creek, Cat Creek, and Rock Creek and elsewhere on the west side of the valley, seem to be parts of the same flow or at least to belong to closely related flows in all three canyons. The bed may actually be continuous through the hill from one canyon to the other,

but this is not evident. The high points between the canyons, such as Chiquita Peak, seem to be local extravasations through the andesitic sheet.

WEST OF MONTE VISTA.

In the foothills 6 miles west of Monte Vista the flows, dipping eastward more steeply than the slope of the hills, form "hogbacks." Several miles farther west, at the limekiln, a normal fault, bearing N. 30° W., with a throw of 50 or 60 feet to the west, has been prospected through a distance of three-fourths of a mile. Throughout this extent the brecciated fault zone is filled with a vein deposit of calcareous onyx, which has been burned for lime but has not yielded any blocks of onyx marble of commercial size. The width from wall to wall varies from 20 to 40 feet, though at the widest places a portion of the space is taken up by slabs of the country rock, which seem to be either mica andesite or mica rhyolite.

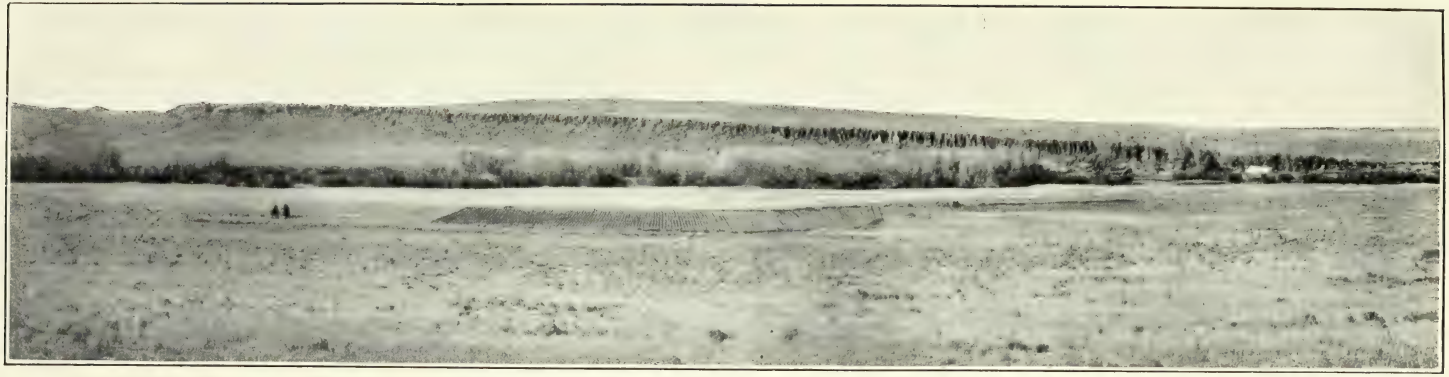
A darker, heavier flow, later than the mica andesite and probably corresponding to the upper flow at the foot of Alamosa Creek canyon, outcrops in a few places, notably near the railway cut midway between Monte Vista and Del Norte, and also in the isolated hill La Loma del Norte, across the Rio Grande, 2 miles east of the last-mentioned exposure.

VICINITY OF SAGUACHE.

The eastern edge of the La Garita Hills from Del Norte to Saguache was not examined, but what appears from a distance to be the pink mica andesite occurs in great massive bluffs and makes up a large part of the hills. In the vicinity of Saguache there are a number of small hills of basic lava, the result of local extravasation. The hill near the cemetery southeast of the town is made up of olivine diabase and hornblende andesite. To the northeast, in the vicinity of Hunt Springs, similar hills appear; also farther northeastward to the vicinity of Villa Grove. North and south of that locality, skirting the edges of the foothills, are heavy outcrops of Carboniferous rocks dipping 50° E.

AGE OF THE ROCKS INVOLVED IN THE WEST RANGES.

In the discussion of the mesa northwest of San Luis village, the northwest prolongation of the San Pedro Mesa, its equivalence in age with the basic lava capping the lava conglomerate series making up the western ranges is suggested (p. 39). There also is noted the correlation of the San Pedro Mesa and its extension with the lava-capped mesa near Fort Garland, which Hayden, following the formation up the Rio Grande from its type locality, identified as the Santa Fe formation, later shown by Cope to be of Miocene age. This will be assumed, then, to be the age of the alternating series of andesite flows and conglomerates of the eastern border of the western hills.



A. PAINTED ROCK BLUFF ON CAT CREEK.

B. SODA LAKE.

Indeed, Hayden [a] noted the occurrence of the Santa Fe formation at the base of the western mountains south of Saguache Creek. The similarity of constitution on the opposite sides of the valley supports the tentative correlation.

GLACIATION OF THE WEST RANGES.

While evidence of glaciation in the upper courses of Conejos River and La Jara, Alamosa, Cat, and Rock creeks is plain, the lower limit reached by the ice in each course is difficult to determine. Distinct terminal moraines are not present, but instead the unquestioned drift of the upper courses becomes thinner and less characteristic in the lower courses and may be succeeded by one or two sets of terraces.

The Alamosa Creek glacier manifestly occupied the U-shaped valley of that creek down nearly to the "box canyon," spreading across the flat west of Chiquita Peak into the valley of Cat Creek and coalescing with the ice in that valley. Below the "box canyon" there are two terraces, both developed on the south side of the valley. The lower one, apparently alluvial, is 60 feet high and 100 to 150 yards wide. The upper one, 30 feet higher, is covered with bowlders, in part glacial, and has an irregular surface apparently morainic in origin—an appearance that is borne out by the arrangement of material so far as that can be seen. A mile farther down the creek a third terrace sets in 35 feet high above the valley bottom. Upon the surface of this terrace are two and in places three trains of bowlders, roughly parallel, steeper toward the creek and sloping toward the valley wall. They appear to be morainic in origin, though the occurrence of the alluvial terrace higher up the creek seems to cast doubt upon such interpretation.

In Cat Creek valley the disposition and character of the drift that lies upon the andesite at the quarry near the lower end of the canyon, as well as of that on the sides of the canyon all the way up, seem to point to their deposition directly by the ice. The two forks of the creek occupy trenches cut in the eastward extension of the glaciated flat west of Chiquita Peak. No terminal moraine is apparent.

The headwaters of Rock Creek rise in the rolling glaciated amphitheater shown in Plate II, *B*. In the vicinity of the forks of the creek there is much evidence of glaciation. Parallel to Painted Rock Bluff, but on the south side of Rock Creek, there is a long terrace, steep in front, the gravel-covered surface sloping gently away from the creek. This terrace is in all respects like the uppermost terrace of Alamosa Creek and apparently is lateral morainic in character.

No further evidences of glaciation were noted on the west side of the valley. There are no indications about Del Norte that the Rio

[a] First, Second, and Third Ann. Repts. U. S. Geol. and Geog. Survey Terr., p. 176.

Grande glacier reached that point, and at Saguache there are no signs of glaciation. Though farther west these stream valleys must have held Pleistocene glaciers, the conditions were such that they did not extend as near to the San Luis Valley in this locality as did those farther south.

THE EAST RANGES.

STRATIGRAPHY AND STRUCTURE.

Commencing north of Poncha Pass, the Sangre de Cristo Range forms a true sierra extending southeastward and culminating in the massif of the Sierra Blanca group of peaks. The sky line, formed by a series of pointed peaks with intervals of sharply serrate and jagged crest line, and the precipitous front, rising abruptly from the level plain to the height of a mile, combine to make this range one of the boldest and most majestic in the country.

The geologic boundaries in this range, as laid down on the Hayden map, are very much at fault. Only the most cursory examination has been made of the range, which has been ascended or crossed by geologists but a few times at most. The formations involved, so far as known, are basal gneiss, schists, and granite; intrusive granite; quartz conglomerate; pudding-stone conglomerate and red sandstone; and limestones and shales. The ages assigned to these formations by the Hayden geologists are as follows: Gneisses, schists, etc., Archean; pudding-stone conglomerate and red sandstone, upper Carboniferous; and limestone and shales, lower Carboniferous.

Reference has been made to the occurrence of limestones and sandstones in the vicinity of Villa Grove. The outcrops, as laid down on the Hayden map, show lower Carboniferous rocks facing the valley and upper Carboniferous behind and above. The dip is toward the valley, thus indicating an overturn. On the east side of the valley the same distribution of formations is represented, the upper Carboniferous forming the upper flanks of the Sangre de Cristo Range, the lower Carboniferous restricted to two outcrops on the western foot of the range. This stratigraphic arrangement, taken in connection with the described anticlinal structure of the range, is altogether improbable. Lee has recently shown [a] for the Culebra Range that the limestones marked on the Hayden map as lower Carboniferous are in reality upper Carboniferous and lie on the basal Archean granite, indicating the entire absence of lower Carboniferous; and this is probably true for the whole range except the north end near Salida, where lower Carboniferous limestone carrying fossils with a strong Devonian facies is known. If the same mistake that was made in the Culebra has been made in regard to the age of the limestone east and west of Villa Grove, the structural difficulty disappears and the range is readily interpreted as a great anticline and the valley as a great

[a] Jour. Geology, vol. 10, 1902, pp. 393–396.

WILLOW CREEK PARK

A typical gathering ground in Sangre de Cristo Range of streams delivering water to the artesian system.

syncline, the limestone being younger and overlying the sandstones and conglomerates. That the structure of the range is not a simple anticline, however, is well shown by a section up the canyon of Willow Creek, which leaves the mountains 2 miles southeast of Crestone. A view looking up the valley from Willow Creek Park is shown in Plate V. The prominent ledge just beyond the middle of the picture dips south of west 70° to 80° and consists of conglomerate. This is the formation which was called "Arkansas sandstone" by Endlich and which has here been spoken of as pudding-stone conglomerate because many of the bowlders in the conglomerate are themselves conglomeratic. Some of the bowlders are immense, Emmons[a] noting some 25 to 50 feet in diameter. The pebbles and bowlders are of crystalline rocks of various kinds and colors. Up the valley the dip approaches the vertical, then is inclined the other way, getting lower, and at the head of the valley the structure develops into the possibly faulted syncline shown in Plate VI, reproduced from a photograph taken near and looking toward the crest of the range. The creek from its source to the lower lake, a distance of 3 or 4 miles, flows approximately along the axis of the syncline. There is probably a closely appressed anticline between Willow Creek Park and the syncline just mentioned. The conglomerate extends all the way from the upper end of the park to the crest of the mountain. The texture seems to grow finer upward, becoming practically that of a coarse reddish sandstone at the axis of the syncline, but about the head of the creek the rock is coarsely conglomeratic again. Making allowance for the appressed anticline, the thickness of the conglomerate, as can be seen, is enormous, so that the question of the source and origin of the conglomeratic material may well be difficult, as Emmons found it.[b]

The axis of the range is in general made up of intrusive granite flanked on either side by conglomerate, though the conglomerate extends across the crest of the mountains near Electric Peak and the head of Willow Creek. Beginning north of Crestone, a band of the older granite sets in, widening toward the south until, with the backbone of later intrusive granite, it takes in the whole range, the sedimentary rocks south of Music Pass being restricted to the east foot of the range.

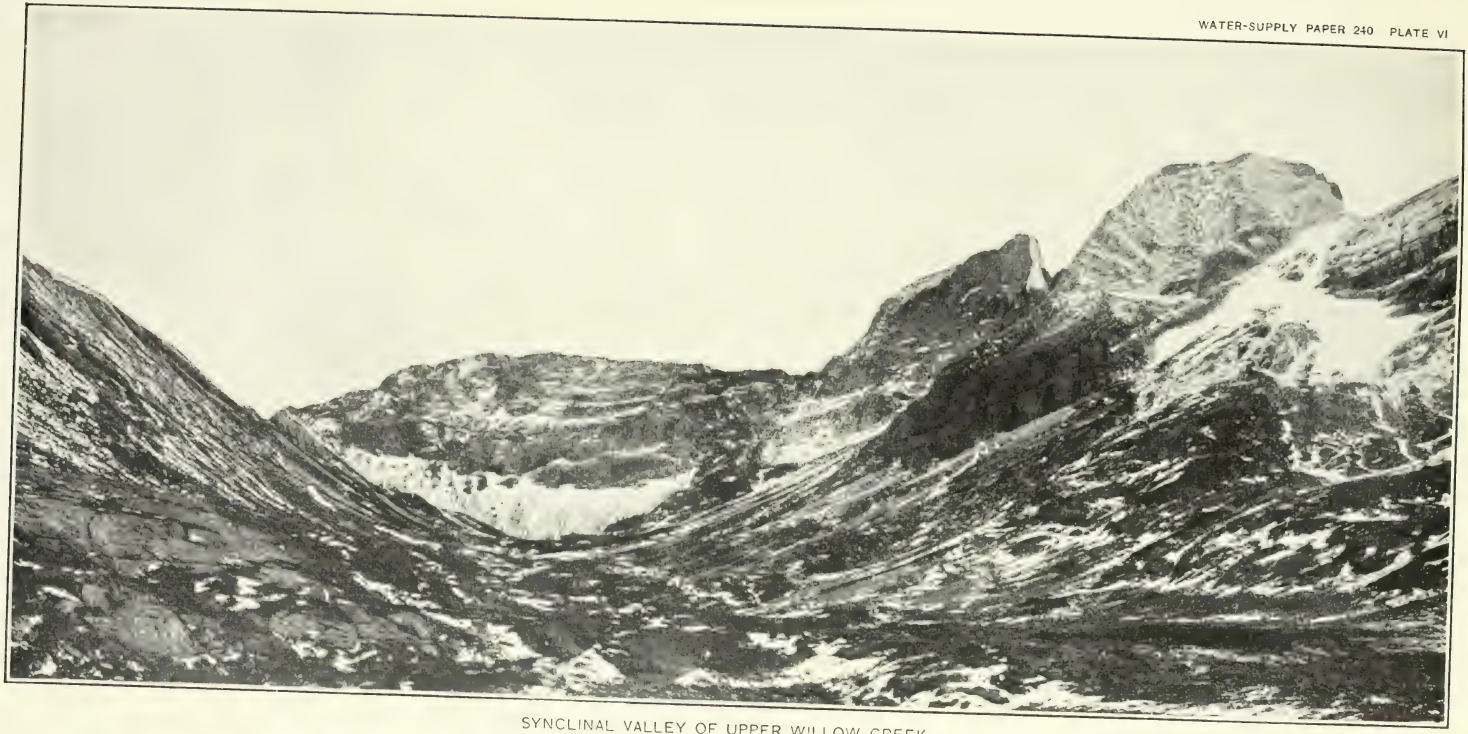
In the saddle between Baldy and Blanca peaks is a bed of conglomerate which is quite different from the conglomerate in the north end of the range, in that the pebbles, which rarely exceed 1 or 2 inches in diameter, are all of pure quartz, while the bowlders of the Carboniferous conglomerate are large and are made up of all sorts of igneous rocks. This conglomerate in the gap has a thickness of a hundred feet or so, rests on the granite, and has a very ferruginous

[a] Bull. Geol. Soc. America, vol. 1, p. 262. [b] Op. cit., p. 265.

sandy matrix, the reddish color showing at a long distance. Down Ute Creek the conglomerate is more pronounced in character, and it lies against the foot of Baldy Peak upon the truncated edges of steeply dipping and intruded crystalline rocks. Its apparent thickness is over 100 feet, and the dip is 14° to 16° N. 15° E. It stretches away north of Baldy Peak down the valley of Huerfano River, with a dip of 8° or 10° in a direction north of east. On the north side of the valley the dip of the contact, which from the crumpled condition of the conglomerate seems to be a plane of movement, is 36° in a direction south of east. To the east the dip is more gentle, 20° in the same direction. In the distance down the north side of the valley can be seen bare white patches of limestone or light shales. No doubt the upward formations succeeding the conglomerate above would be shown in a section down the ridge in the direction of the dip, and perhaps also the relation of the conglomerate to the conglomerates and limestones of the northern part of the range and of Veta Pass. These relations not having been ascertained, the age of this conglomerate must remain for the present undetermined. An apparently similar series of rocks in the Culebra Range just east of San Luis has been described by P. H. and E. C. van Diest, as will be noted below.

Though it is marked on the Hayden maps as Archean, both Hayden and Stevenson pronounced the mass of the Blanca group to be of intrusive rock. For the most part, and particularly in the western portion, it consists of coarsely crystalline granite, without plication or schistosity, but with a system of northeast-southwest joints and fissures. Gneissic and schistose rocks make their appearance along Ute Creek, as noted below. Also, in the lower foothills immediately south of Blanca Peak, the rocks are gneiss or gneissoid granite, the laminæ striking northeast and southwest similarly to the veins and fissures in Blanca Peak.

The outcrops in La Veta and Sangre de Cristo passes and to the west, lying as they do on the great highway into the valley, have been noted by Schiel, Hayden, Ruffner, Endlich, and others, and Lee has collected fossils from them. The beds are red sandstone, conglomerates, shales, and limestones. Endlich states that where the sandstones appear from beneath the eastern Cretaceous in the pass they stand nearly vertical but incline to the east, the dip becoming lower toward the central mass of intrusive rock to the west, beyond which the sandstones and limestones set in again, with the dip reversed, and soon pass under the axis of a syncline. Beyond the syncline the limestones are involved in a very acute anticline and the west line of the anticline is faulted so that it abuts squarely against the basal granite. Hayden and Endlich both pronounced these limestones to be upper Carboniferous, and collections by Lee agree



SYNCLINAL VALLEY OF UPPER WILLOW CREEK.

Showing structure of Sangre de Cristo Range and barren character of the upper drainage basins of that range as contrasted with those of the western ranges. (See Pl. II, *B*.)

with this determination. A similar series, but with different orographic features, is described by Endlich as occurring at the head of Indian Creek. In the ninth report of the Hayden Survey, for 1875, Endlich describes a section (No. VIII) of the east side of the Culebra Range about halfway between Culebra and Trinchera peaks. The lower Carboniferous limestone is represented as lying on the east flank of the granite backbone and overlain in turn by red upper Carboniferous sandstones, whose dip becomes steeper to the east until they disappear beneath the vertical outcrop of Dakota sandstone in "Stonewall" Valley. Lee [a] has shown by a good collection that the limestone is upper Carboniferous and expresses the opinion that the red sandstones belong to the "Red Beds."

E. C. and P. H. van Diest [b] describe a block of quartzites and siliceous limestone faulted against the granite at a locality on the Rito Seco, about 9 miles northeastward from San Luis. The lowest member is a thin bed of conglomerate, composed of light bluish and greenish pebbles of quartz cemented by oxides of iron and manganese. Above this come 160 feet of white saccharoidal quartzites overlain by a thin bed of shale and 200 feet of light-gray siliceous limestones, and those in turn are topped by darker limestones. The fault which throws them against the granite on the east bears N. 35° E. and dips 52½° NW. The formations themselves dip 5° or 6° E., into the mountains. No fossils were found, but on the basis of lithology the authors assign the quartzites to the Cambrian and the limestones to the Silurian.

While developed on a much smaller scale here, the conglomerates as described bear a striking resemblance to those on upper Ute Creek. It will be recalled that farther down the ridge from the outcrop described north of the Huerfano, and overlying it, several bare white spots were noted. It seems altogether probable that these represent a greater development of the limestones overlying the quartzite of the Rito Seco.

Enough has been said to indicate that little is actually known of the geology of the Sangre de Cristo and Culebra ranges and that it is an inviting field for closer study.

GLACIATION OF THE EAST RANGES.

The various stream valleys heading against the crest of the Sangre de Cristo Range all held Pleistocene glaciers, the morainic remains of which fall into two systems showing the existence of two periods of glaciation. The moraines ordinarily reach down to about 9,500 to 9,000 feet above sea level and crown the summits of the great alluvial cones that spread out from the mouths of the stream canyons. The moraines of both systems are comparatively fresh looking, and the

[a] Jour. Geology, vol. 10, 1902, pp. 393–396. [b] Proc. Colorado Sci. Soc., vol. 5, 1894, pp. 76–80.

outer, older ones are not noticeably more eroded than or different topographically from the inner, later ones. Some of the inner moraines are lower, some higher than the outer ones, and though they are generally shorter than the older moraines, some of them, as in Bear Creek valley, transgress the older moraines and extend farther out upon the alluvial slopes, these irregularities being due presumably to varying local climatic conditions in Pleistocene time.

Black Canyon, just east of Orient, has lateral moraines on either side of the valley, 100 to 200 feet high and reaching to the alluvial slope at the mouth of the canyon. A prominent moraine juts out from the Willow Creek canyon, east of Crestone. Behind the moraine is the park or meadow shown in Plate V, the bed of an extinct glacial lake. Two existing glacial lakes are found in the U-shaped valley above the park, as well as striæ, roches moutonnées, and other evidences of ice occupation. South Zapato Creek valley, heading in the Blanca massif, exhibits the same evidences of ice occupation, together with a double crescentic moraine crowning a great alluvial fan at the height of 1,500 feet above the level of the valley. The inner moraine formerly inclosed a small lake, the outlet of which cut through the moraine where it adjoined the canyon wall on the north side and, once incised in the rock, has continued to cut back a narrow winding cleft, through which the water pours, forming the picturesque Zapato Falls. Middle, Bear, Little Bear, Blanca, and Ute creeks, the circle of radiating streams flowing down the west and south sides of Blanca Peak, each held a glacier which came down to and terminated upon the apex of its alluvial fan. At the head of Huerfano Valley, snugly under the northeast face of Blanca Peak, there yet remain two small characteristic glaciers.[a]

The Culebra Range suffered glaciation to a similar extent, according to Willis T. Lee.[b]

SAN LUIS HILLS.

Stretching northeastward across the valley from Antonito to Fort Garland is a series of basaltic hills, flat topped and higher west of the Rio Grande, lower and more rounded east of the river, degenerating into a lava-capped mesa, the north border of which forms an escarpment along the south side of Trinchera Creek. At a point 5 miles southwest of Fort Garland this escarpment swings south, joining the San Pedro Mesa at San Luis. These hills and mesas form the southeast limit of the artesian basin, the sand and clay beds of which abut against the older formation, numerous springs coming up along the contact, particularly in the lower course of Conejos River. This

[a] For a fuller description of these glaciers and the Pleistocene glaciation generally see Jour. Geology, vol. 15, 1907, pp. 15–22.

[b] Personal communication.

contact in all probability marks a fault scarp, the older strata forming the west ranges and the floor of the valley being deeply downthrown to the northwest in the formation of the depression in which the sands and clays of the artesian system were deposited.

THE VALLEY.

In the San Luis Valley there may be distinguished two classes of more or less unconsolidated gravels, sands, and clays, an older series of conglomerates with intercalated lava flows, and a younger overlying series of blue clays with interstratified sand beds.

SANTA FE FORMATION.

The older conglomeratic series makes up the small isolated mesas and the higher foothills about Fort Garland and southward along the western base of the Culebra Range, as well as the basalt-covered San Pedro Mesa and its northward continuation which has been mentioned in the discussion of the San Luis Hills. Hayden [a] describes these mesas and refers them to the Santa Fe formation. A thin section of some of the consolidated sands from beneath the lava in the north end of the San Pedro Mesa near San Luis shows, microscopically, a prominent calcareous cement. The sand itself is in part volcanic débris and in part of aqueous origin. The age of the Santa Fe formation has been shown by Cope [b] from well-known and characteristic vertebrate remains to be Miocene. The mesas east and south of Fort Garland are capped by a flow of basalt, while sheets of the same rock are interbedded with the gravels and sands of which the mesas are composed.

A series of deposits northwest of Fort Garland, the "compact drift" of Endlich,[c] deserves notice. A great alluvial fan that formed on the left fork of Ute Creek has been trenched by the creek and shows a succession of terraces. Northwest of Fort Garland a mesa approximately 150 feet high is apparently a portion of this fan, which, with others formed by the other streams that converge at Fort Garland, filled up the angle of the valley between the Blanca group on the northwest and the basalt-capped mesa southeast of Garland. The mesa is covered with a sheet of gravel ranging from pebbles up to bowlders 12 inches in diameter, and is made up of fine buff sand or unindurated sandstone, with here and there a gravel layer consisting of various kinds of crystalline rocks, the whole dipping 10° or 12° E. In the next mesa due west, up the draw, the dip of the soft sandstone is somewhat steeper, ranging from 12° to 22° in a direction north of east. Some of the sandstone beds are quite indurated. No fossils are to be observed. The dip continues on across the mesa for a

[a] Ann. Repts. U. S. Geog. and Geol. Survey Terr., 1867, 1868, and 1869, p. 175.
[b] Ann. Rept. Chief of Engineers for 1874, Appendix FF, p. 127.
[c] Ann. Rept. U. S. Geol. and Geog. Survey Terr., 1875, pp. 149, 222.

mile, but shifts to the south. Toward the west edge of the mesa the high points are composed of igneous rocks projecting through the sands. Within 200 yards of the igneous rock the sandstone becomes more and more bowldery, until in the immediate neighborhood of the igneous rock it is composed almost exclusively of bowlders and all stratification is lost. The igneous rock has not been intruded into the sandstone, for the contact is everywhere such as would result from the deposition of the sandstone upon a surface that had been subject to subaerial weathering. Distinguishing these beds from Tertiary lake beds under the appellation "compact drift," Endlich correlated them with the valley glacial drift of the Sangre de Cristo Range, though believing them to belong to an early stage of the glaciation. Hayden referred them to the Santa Fe formation, and the present writer coincides in that correlation.

Another occurrence of the older material is in the great sand dunes west of Mosca Pass. Endlich [a] regarded the dunes as of recent origin and derived from the drifting sands of the valley, but Hayden [b] referred them to the Santa Fe formation. For the reasons given on page 48, Hayden's is regarded as the true interpretation.

No fossil remains are known to have been found in the Santa Fe formation within the limits of the San Luis Valley, its age determination depending upon localities farther south in the Rio Grande valley.

ALAMOSA FORMATION.

To the younger upper series of blue clays with interstratified water-bearing sand beds, which occupy the bottom of the valley proper, the name Alamosa formation has been given,[c] from the town of that name near the center of the valley.

The low relief of the valley region renders natural exposures of the Alamosa formation very scarce, the best one being afforded by Hansen Bluff (Pl. VII, *B*) on the east bank of the Rio Grande, nearly east of the Peter Hansen ranch house.

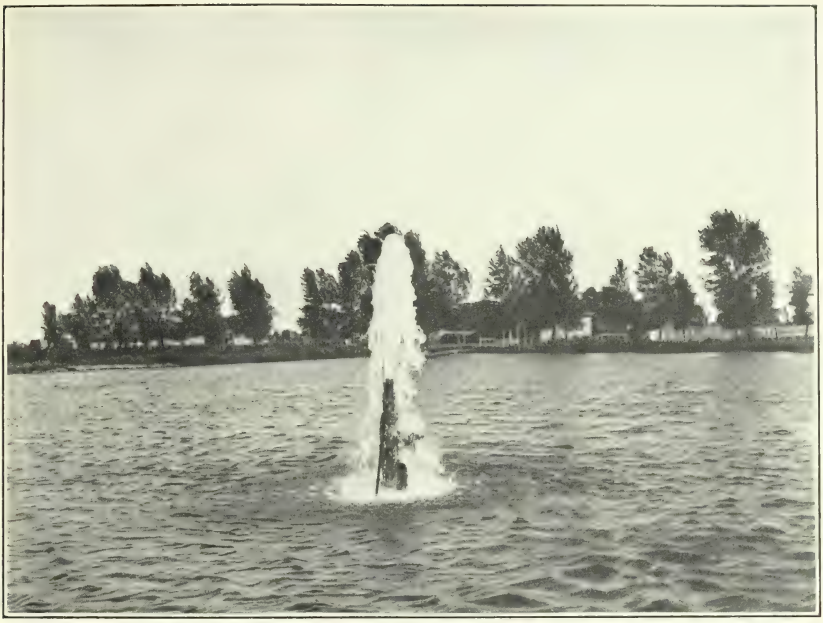
Section of Alamosa formation in Hansen Bluff.

	Feet.
Recent:	
Gravelly slope	4
Conglomerate, indurated sandy clay matrix	4
Alamosa formation:	
Fine gravel and sand, loose	3½
Fine-grained reddish sand	2½
Black and red sand	½
Drab joint clay, with a great many white indurated nodules	1½
Coarse indurated sand and small quartz pebbles	4

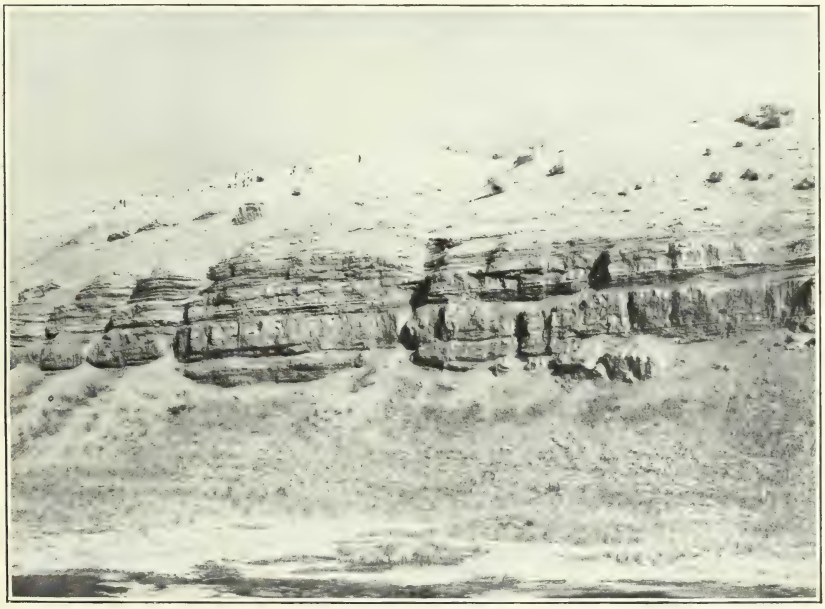
[a] Ann. Rept. U. S. Geol. and Geog. Survey Terr., 1875, p. 143.

[b] First, Second, and Third Ann. Repts. U. S. Geol. and Geog. Survey Terr., p. 176.

[c] Siebenthal, C. E., The San Luis Valley, Colorado: Science, new series, vol. 31, No. 802 (May 31, 1910), pp. 744-746.



A. BUCHER WELL.



B. HANSEN BLUFF.

Showing stratigraphy of the Alamosa formation.

Alamosa formation—Continued.	Feet.
Buff to light-drab sandy clay	10½
Fine and coarse sand in laminæ	5½
Olive-green sandy joint clay, with shells	2½
Banded drab sand, with clay pockets	1
Fine and coarse pebbly sand in indurated laminæ	4½
Loose black sand	1½
Fine banded clayey sand	1½
Coarse sand and clay, with quartz pebbles	2½
Débris slope to river	12
	61½

The following well section at Alamosa will illustrate this formation to a depth of 725 feet:

Section of Alamosa formation, from record of Spriesterbach well.

	Thickness.	Depth.
Recent:	*Feet.*	*Feet.*
Soil and clay	3½	3½
Coarse sand	15½	19
Alamosa formation:		
Clay	2	21
Sand	6	27
Clay	6	33
Sand	3	36
Clay	4	40
Sand	5	45
Clay	11	56
Sand	3	59
Clay	17	76
Sand	1	77
Clay	23	100
Lumpy black clay	4	104
Clay	113	217
Sand (first flow)	4	221
Clay	249	470
Sand (second flow)	7	477
Very hard clay	90	567
Sand (third flow)	13	580
Hard clay	20	600
Very soft sandy clay	60	660
Hard clay	6	666
Sand (fourth flow)	30	696
Hard clay	14	710
Sand (fifth flow)	13	723
Hard clay	2	725

It is more than likely that minor alternations of sand and clay below a depth of 100 feet have not been taken into account in the record above. The following log of a well on the ranch of Mr. D. E. Newcomb in the SW. ¼ sec. 22, T. 36 N., R. 10 E., will illustrate this point:

Section of Alamosa formation, from record of well on D. E. Newcomb's ranch.

	Thickness.	Depth.
Recent:	*Feet.*	*Feet.*
Soil	14	14
Gravel	8	22
Alamosa formation:		
Light clay	30	52
Coarse dark sand	11	63
Brittle clay	4	67
Blue clay	11	78
Fine clay	1½	79½

Section of Alamosa formation, from record of well on D. E. Newcomb's ranch—Continued.

	Thickness.	Depth.
Alamosa formation—Continued.	*Feet.*	*Feet.*
Clay	1	80½
Sand	½	81
Clay	1½	82½
Sand	4½	87
Clay	4	91
Sand	1	92
Clay	1	93
Sand	½	93½
Blue clay	6½	100
Sand	1	101
Clay	4	105
Sand (strong flow)	14	119
Hard blue clay	5	124
Sand (flow)	2	126
Clay	2	128
Sand	1½	129½
Clay	3½	133
Sand	3	136
Clay	4	140
Sand	6	146
Clay	2	148
Sand	7	155
Clay	1	156
Sand	9	165
Clay	5	180
Sand	5	185
Clay	5	190
Sand	10	200
Clay	12	212
Sand	1	213
Clay	2	215
Sand	2	217
Clay	7	224
Sand	2	226
Clay	7	233
Sand	3	236
Red clay	9	245
Sand	3	248
Clay	1	249
Sand	1	250
Clay	1	251
Sand	7	258
Clay	5	263
Sand	5	268
Clay	3	271
Sand	1	272
Clay	7	279
Sand	3	282
Clay	5	287
Sand	2	289
Clay	1	290
Sand	2	292
Clay	2	294
Sand (flow)	12	306
Clay	3	309
Sand	4	313
Clay	14	327
Sand	2	329
Clay	1	330
Sand	7	337
Clay	5	342
Sand	3	345
Clay	2	347
Sand	2	349
Clay	3	352
Sand	6	358
Clay	2	360
Sand	3	363
Clay	5	368
Sand	4	372
Clay	1	373
Sand	½	373½
Clay	2½	376
Sand	9	385
Gravel	3	388
Sand	6	394

This well, with over eighty changes in the character of material penetrated in less than 400 feet, will show the impossibility of correlating the well records one with another or of constructing any other than an ideal section of the valley. The multiplicity of wells in the valley, the rapidity and monotony of changes in the formation, and the short time involved in sinking the average well combine to discourage the systematic preservation of well records. Only occasionally, when the person having the well sunk is especially interested, is there any record kept. Most drillers in the valley are perfectly acquainted with their particular field and know beforehand at what depth, within a narrow margin, the desired flows will be found. Several wells are deeper than the Spriesterbach well, but there is only one other deep well with an accurately kept record. The Bucher well at Alamosa is over 1,000 feet deep, the Denver and Rio Grande Railroad well at Moffat is 1,045 feet deep, and the "oil well" east of Mosca is 1,283 feet deep, and several others are over 1,000 feet, but of these there is a record only of the "oil well," which is as follows:

Section of Alamosa formation, from log of well No. 1, Chicago and San Luis Oil Company, SW. ¼ SE. ¼ sec. 5, T. 39 N, R. 11 E.

	Thickness.	Depth.
	Feet.	*Feet.*
Recent:		
Sand and clay	30	30
Alamosa formation:		
Blue clay	4	34
Black sand	16	50
Fine sand and clay	41	91
Blue clay	5	96
Blue clay and fine sand (water, small flow)	148	244
Blue clay (more water, some gas)	125	369
Fine white sand (more water, some gas)	8	377
Hard blue clay	9	386
Sand, with bones and shells (flow of gas)	6	392
Clay shale	25	417
Fine sand	20	437
Fine green sand	5	442
Clay shale, hard, with plentiful shells (gas increasing)	42	484
Blue clay and sand (strong water, with gas)	198	682
Blue sand (strong water, with gas)	53	735
Black sand (strong water, with gas)	42	777
Hard clay (strong water, with gas)	26	803
Hard clay, streaks of sand (strong water, with gas)	84	887
Clay shale (strong water, with gas)	81	968
Clay and sand (strong water, with gas)	7	975
Hard blue shale, shells and moss	111	1,086
Softer blue shale	72	1,158
Harder blue shale	68	1,226
Blue shale	45	1,271
No record	12	1,283

The foregoing sections display as well as possible the constitution of the Alamosa formation. Its contact with the underlying Santa Fe formation, though nowhere exposed, is readily shown to be one of unconformity. Some of the deeper flowing wells to the southwest end in what is called the gravel flow, beyond which the drilling machines used in the valley are not able to go. Still farther south and west, outside of the limit of flowing wells, there are a number

of wells which, after passing through the series of clay and sand beds and a basal gravel bed, penetrate a sheet of lava, below which various gravel and pumice beds are found. Without question the lava and the beds beneath it belong to the Santa Fe formation. The wells of which there are records are too widely scattered to show whether the lava sheet has an erosional configuration or not, but near the point where the Rio Grande enters the San Luis Hills the Alamosa formation abuts against the lavas of those hills at the surface and presumably against the gravel beds of the Santa Fe formation beneath the surface. So, too, the topography exhibited by the foothills of the Culebra Range, composed as they are of the Santa Fe formation, is of a much older type than that of the Alamosa formation.

Though it is impossible to correlate well sections that are any great distance apart, or to trace any stratum of clay or sand from point to point, nevertheless the experience of drillers is that the "first flow" (and by inference, the successive lower flows) in any neighborhood is found at very near the same horizon or depth, gradually increasing in depth toward the center of the valley. For instance, the first flow in the region of Monte Vista is at about 100 feet, near Parma 175 feet, and at Alamosa about 250 feet. Between Center and Hooper the first blue clay is struck at about 80 feet along the entire distance. At Center the first flow, a very small one, is found at 155 feet, at Garnett the first flow is at about 175 feet, and at Hooper and Mosca at about 200 feet. That the uppermost water-bearing bed is covered by a stratum of clay persisting from the center of the valley to the receiving area in the gravelly alluvial slope at the edge of the valley is likewise indicated by the fact that the water is not alkaline. If the bed came to the surface anywhere inside the irrigated area of the valley, it would necessarily absorb more or less alkali from the irrigating waters. Even in the Mosca-Hooper district, where the tinted deeper waters are highly alkaline, the uppermost flow is clear and potable.

The cross section in figure 3, though largely ideal, is based upon all the data available. A fact that comes out in the construction of this section is that wells near the center of the basin show heavy clay beds and fewer aquifers; that wells nearer the margin of the valley, but not too close to it, show thinner clay beds and more aquifers; whereas wells at the limit of the flowing-well area, or outside that line, show but few and thin beds of clay, with sand largely predominating. This is but an expression of the physical limitation of sedimentation. Sand, being coarser and heavier than clay, would be expected to constitute the bulk of the deposits near shore—that is to say, near the edge of the valley—while the finely divided clays would make up the greater volume of the formation in the center of the valley. Beds of sand, thinning toward the center of the valley, pinch out before reaching that region, and beds of clay thin out before

reaching the margin of the basin. Thus the region where both clay and sand beds exist in greatest number is a band of indefinite width which circles the basin some distance inside the margin of the flowing-well area. These features are shown in the diagram (fig. 4). If it be argued that the lower aquifers, having the heaviest pressure, must be confined by clay beds which extend farther up the alluvial slope in the region of intake, it should be remembered that the pressure where the wells are numerous is dependent largely on their number. The deeper the aquifers the fewer are the wells that reach them. Of two aquifers drawing from a common bed of sand in the marginal region, and divided by a clay septum only part way back from the wells, and hence theoretically with identical pressures, the lower one will nevertheless exhibit the higher pressure if the upper one is more drawn upon by wells.

Attention has been called to the great development of alluvial fans and slopes about the sides of the valley. The great Rio Grande fan occupies a fourth or more of the whole extent of the valley bottom. From the figures which have been given of the depth to the first flow at various points on this fan it is evident that the configuration of the uppermost aquifer agrees closely with the surface of the fan, at least within the limits of the artesian basin. The formation of the fan up to the horizon of the upper water-bearing sand must therefore have gone on step for step with the deposition of the Alamosa formation. In other words, the flat alluvial fan of the Rio Grande, with the exception of the gravel veneer, is of sublacustrine deposition, and the fans of the other streams on the west

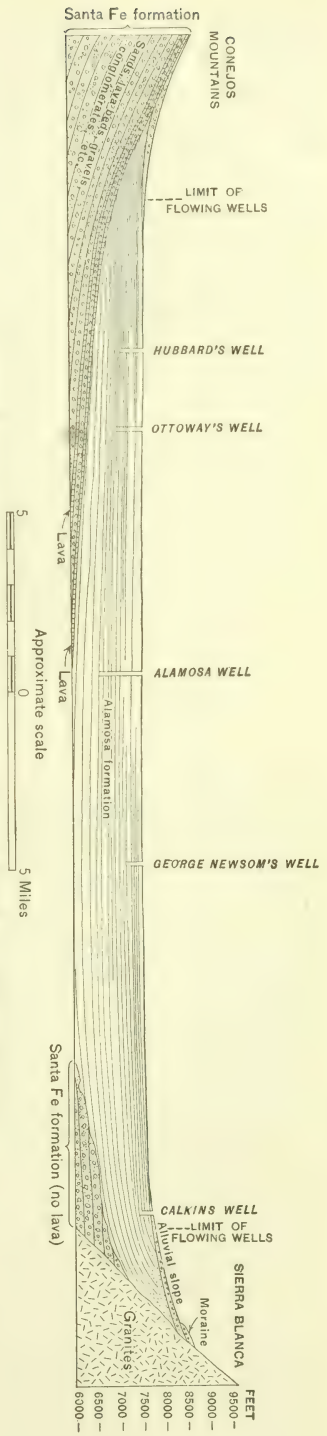


FIGURE 3.—Cross section of San Luis Valley from foot of Blanca Peak to foot of Conejos Range.

side of the valley are largely of the same origin. The persistency and continuity of the thin beds of sand and clay making up the Alamosa formation show that this deposition was in the quiet water of the lake at some distance from the mouths of the streams. Near the stream mouths the sedimentation would naturally take on the shifting character of delta formation. If sediments of this character occur in the Alamosa formation, they are to be expected in the highest part of the fans and on the border of the artesian basin.

Though it does not exhibit the close relation of topography and structure shown by the Rio Grande fan, the alluvial slope along the west base of the Sierra Blanca is nevertheless shown, by the occurrence of artesian water well up the slope, to be made up of the alternating clays and sands of the Alamosa formation. Aside from a certain lack of correspondence, as shown by the topographic map, between the topography and the limit of the flowing-well area, there is no apparent reason for distinguishing between the age of the fans and that of deposits of the valley proper. The deposit of gravel that veneers the upper portion of the alluvial fans and slopes is probably more recent than the body of the fans. The section (fig. 3) and the

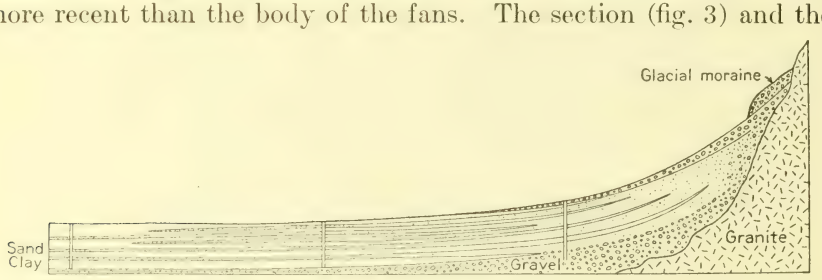


FIGURE 4.—Diagram to illustrate the structure of the artesian basin and the alluvial slope and to indicate the relation of the glacial moraines to the slope.

diagram (fig. 4) illustrate how the glacial moraines of the Blanca Mountains are superposed upon the crests of the fans, which are thus plainly shown to antedate the ice period. The moraine of Zapato Creek is especially well calculated to bring out this relation, because, as explained on a previous page, almost all the postglacial erosion of Zapato Creek has been limited to the north edge of the fan, leaving the front of the moraine surmounting the alluvial fan, practically as it was disposed by the advancing ice tongue.

The age of the Alamosa formation is thus seen to be preglacial and post-Miocene. From the Santa Fe formation it was separated by a period of deformation, which was followed by the outpouring of an extensive series of extrusive lavas, followed in turn by an erosion interval of unknown duration. On the other hand, there was apparently no break in sedimentation and no erosion interval between the deposition of the Alamosa formation and the glacial occupation, which was here rather late in the Pleistocene. The logical inference from this is that the formation is of late Pliocene or early Pleistocene age.

As noted in the section of Hansen Bluff on a preceding page, the stratum of olive-green clay yielded a great number of shells. These were referred to Dr. W. H. Dall, who gives the following list of forms:

Planorbis parvus Say.	Lymnæa desidiosa Say.
Planorbis trivolvis Say.	Valvata lewisii Currier.

Occurring with these forms are countless numbers of minute valves of an entomostracan not identified.

Shells similar to these are reported as brought up in drillings all over the valley. Small hollow white bones, also brought up, are usually referred to as "fish bones" or "bird bones." Bits of wood, rootlets, leaves, seeds, and peaty moss are reported from all over the valley, particularly from the Mosca-Hooper district, which yields the tinted water.

The species enumerated above are all fresh-water forms, and while such an assemblage has in general been referred to the Quaternary, it may equally well be referred to the Pliocene and thus offer no inherent objection to the classification of the Alamosa, on stratigraphic grounds, as either late Pliocene or early Pleistocene.

QUATERNARY DEPOSITS.

The Recent deposits of the valley comprise sand dunes, alluvial fans, alluvium, and alkali-lake deposits.

SAND DUNES.

Incipient dunes occur all over the valley, gathering behind clumps of brush, fence rows, or whatever else offers a wind-break. A particularly sandy area with many small dunes lies south of the Rio Grande between Alamosa and Parma station. Another area lies between Alamosa and Mosca, extending northeastward in the direction of San Luis Lake. The trough of the valley from the railway near Washington Springs northward to Dune station is one succession of small brush-crowned hillocks with interspersed bare places. The latter in the wet season become the sites of ponds and lakelets. Each small lake has an embankment on the north and east shores as a result of the lodgment in the vegetation there of sand picked up by the prevailing southwest wind in its clear sweep across the dry bed and shores of the lake. The San Luis Lakes have such embankments 20 feet high and the Russell Lakes have them in proportion. The alluvial slope at the west base of the Sangre de Cristo Range has much drifting sand and many incipient dunes scattered from Zapato Creek as far north as San Isabel Creek.

The great development of sand dunes, however, is between Medano and Sand creeks, where an area of over 40 square miles is a

solid expanse of dunes, some of which reach great size, as shown in Plate VIII. These dunes consist of rather coarse white quartzitic sand with which is mixed a varying proportion of darker and heavier sand, the latter consisting largely of magnetite, with presumably a proportion of those rare earths ordinarily found in black sands. Several attempts have been made at placer mining in the area but are reported as having been given over on account of the difficulty in bringing water to the deposits. Assays are reported to have shown the darker sands to be high in auriferous magnetite. Be that as it may, it seems undeniable that the sands of the dune area contain a larger proportion of the heavier material than the sand of the valley.

Hayden, as noted, classed the dunes as a remnant of the Santa Fe formation. Endlich[a] advanced the theory that the sand came across the valley from the mountains on the southwest, being driven to its present locality by the prevailing southwest winds, and that it was especially collected in the reentrant angle in the mountain front near Mosca Pass as an effect of eddying currents in the winds, caused by the low gaps in the mountains near this point.

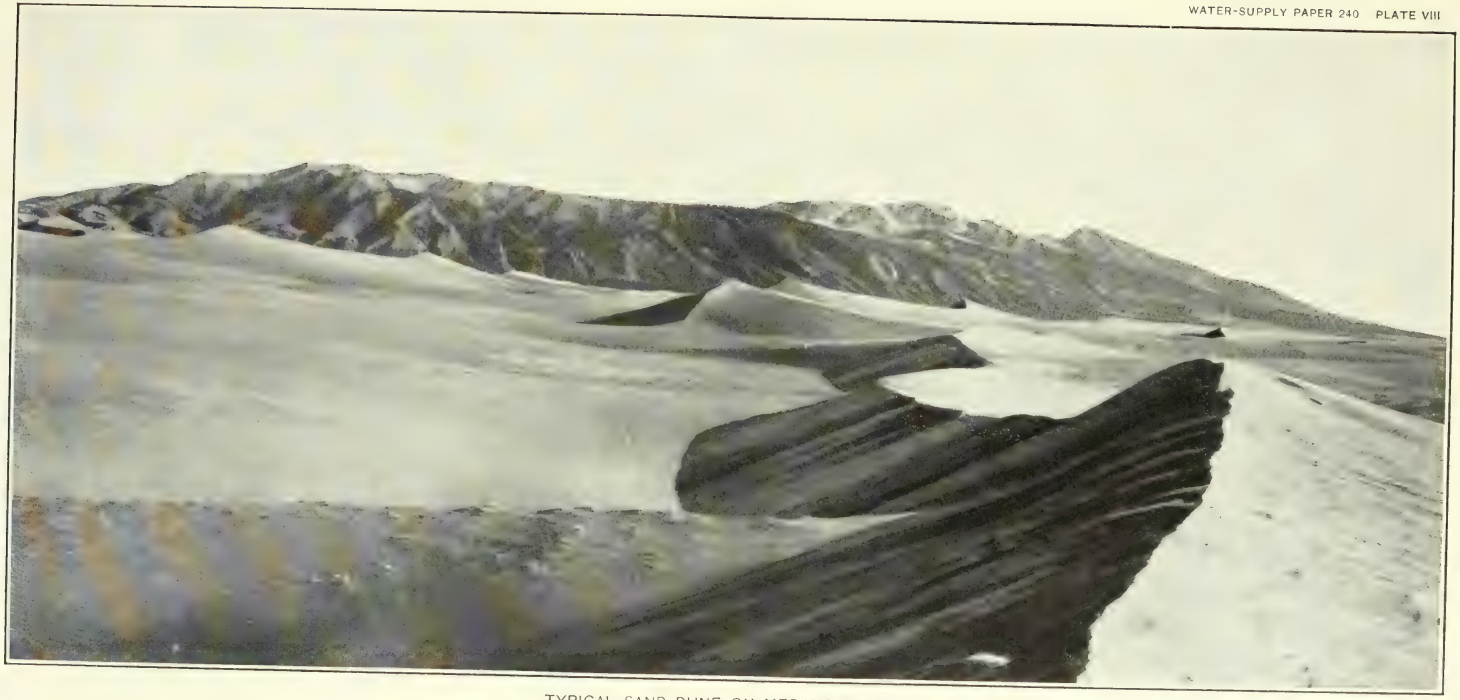
That the sands of the valley are shifting northeastward under the influence of the winds is shown by the long sandy area along the western alluvial slope of the Sangre de Cristo Range and by the embankments of sand on the north and east shores of the lakes and ponds. That the accumulations of the great dune area are so derived is open to question. It has been pointed out that the sand of the dune area averages much heavier than that of the valley in general. In accumulations under such wind transportation and sorting, the reverse would occur. It seems much more reasonable to conclude with Hayden that there was here a remnant of the Santa Fe formation, without the protection of interbedded or overcapping lavas, which has been broken down by the winds, and its sands, whipped now forward and now backward, possibly augmented by contributions from the valley, have been built up into the dunes we now see.

ALLUVIAL FANS.

It has already been shown that the alluvial fans and slopes were essentially completed in preglacial time and that they are probably Pliocene or early Pleistocene in age. But over their surface is a covering or veneering of gravel which must have been largely increased in glacial time and since.

In the description of the topography of the valley (p. 11) reference was made to low bluffs or terraces, not now adjacent to streams, which were explained as old courses of the streams or their distributaries abandoned in their wanderings over the alluvial fans. These

[a] Ann. Rept. U. S. Geol. and Geog. Survey Terr., 1875, p. 143.



TYPICAL SAND DUNE ON MEDANO RANCH.

and the configuration of the fan itself seem to have been interpreted by various writers as due to former courses of the Rio Grande. Carpenter [a] alludes to the "ancient course" of the Rio Grande, but does not locate it on the accompanying map. Hinton [b] describes and maps the old course as leaving the present river above Del Norte, skirting the foothills with a due northeast course to the trough of the valley, which it followed southward, uniting with the present course of the Rio Grande near Hansen Bluff. The course northeast from Del Norte, as outlined on the map, corresponds to the north edge of the Rio Grande alluvial fan. Doubtless the Rio Grande or some distributary in times past took the course along the north edge of the fan, just as the river at present occupies a course along the south edge of the fan, and just as it must have occupied all the intervening territory, wandering backward and forward across it. In this way it must have deposited the gravel and sandy covering of the fan, in the fashion which may be seen after a shower where a gully in a steep slope strikes a more level space and the streamlet drops part of its load and builds up a little alluvial fan. But a wrong impression is conveyed by alluding to it as "the" former course if that is meant to imply that the Rio Grande has had but two courses, that one and the present one.

Endlich [c] outlines a former course of the Rio Grande, leaving the present course of that river 3 miles above Alamosa, circling north of Washington Springs, crossing the railroad near Baldy station, crossing Trinchera Creek south of that station, crossing the Rio Culebra about 6 miles west of San Luis, and rejoining the present course some 15 miles below the New Mexico line. A glance at the topographic map will show the utter improbability of this supposition. Baldy station is 60 feet higher than the point on the river where the old course is supposed to leave and the divide south of Trinchera Creek is 50 feet higher still.

ALLUVIUM.

Alluvial bottoms occur along the Rio Grande and its various tributaries as well as along the other streams which enter the valley but do not reach that river. The width of the alluvium along the Rio Grande varies from 1 to 2 miles, with here and there reaches of gravelly and sandy loam. The habit of the smaller streams to divide into distributaries reuniting again lower down, forming "sloughs" or "bayous," has a tendency to make the alluvial areas of those streams wider than they would otherwise be.

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[a] Bull. Colorado Agr. Coll. Exper. Sta. No. 16, p. 18.

[b] Report on irrigation and the cultivation of the soil thereby: Sen. Ex. Doc. No. 41, 52d Cong., 1 sess., pt. 1, p. 151.

[c] Ann. Rept. U. S. Geol. and Geog. Survey Terr., 1875, pp. 147, 148.

42120°—WSP 240—10——4

ALKALI-LAKE DEPOSITS.

There are many small ponds over the valley which in the dry season are pretty well saturated with alkali, exhibiting a white crust along the shore and upon any object projecting above the surface of the water, but in the SW. ¼ SW. ¼ sec. 30, T. 40 N., R. 12 E.,10 miles east-southeast of Hooper, there is a small lake about an acre in extent which is practically solid crystallized sodium carbonate. The lake has the appearance of being frozen and covered with a thin fall of drifted snow. A view of it is shown in Plate IV, *B*.

This deposit has been examined by Dr. Herman Fleck, of the Colorado School of Mines, and from his report the following facts are taken by the courtesy of Mr. Mark Woodruff, receiver of Colorado state lands: The soda is quite pure, except for a certain amount of dust, including some organic matter, blown into the deposit by the wind and amounting in the average sample to about 15 per cent. The average thickness of the soda is about 18 inches, with a maximum of 30 to 48 inches, and it is estimated that 4,000 tons of soda remains in sight in the lake. About 500 tons has been raised and shipped. As the soda was removed, the space filled with the mother liquor, from which soda is again crystallizing. How long this would continue and to what extent solid soda exists beneath the surface are questions as yet unanswered. The soda, though originally derived by solution from the crystalline rocks of the mountains, probably has its immediate origin in the clays and soils of the valley, from which it has been leached and concentrated, as are the alkali crusts that trouble the farmer. The reason for the especially strong condensation at this single point probably lay in some topographic relation now altered and concealed by the shifting dunes of this portion of the valley.

W. P. Headden[a] has also examined the soda lake and made analyses of the deposit and the mother liquor, of the surface water and alkali incrustations, and of the tinted alkaline artesian waters of the Mosca-Hooper district. He found that the mother liquor of the soda lake and the tinted artesian waters have the alkalies and other elements in common and in like proportion, differing in those respects from the surface waters and the alkali incrustations. He concludes that the soda deposits have been derived in some way from the tinted artesian waters.

GEOLOGIC HISTORY OF THE SAN LUIS VALLEY.

The area occupied by the San Luis Valley was originally included in the eastern portion of the Sawatch land mass, the eastern shore line of which corresponded in position to the Sangre de Cristo-Culebra axis. Upon this shore line, through Paleozoic and Mesozoic time, had been

[a] Am. Jour. Sci., 4th ser., vol. 27, 1909, pp. 305–315.

deposited great thicknesses of limestones, sandstones, and conglomerates. As in other places where a shore line received heavy deposits, it became a line of weakness, and succumbing to the pressure was folded by stages into the towering Sangre de Cristo and Culebra ranges. Correlated with the uplift of the range was a depression of the valley apparently either by a synclinal fold, or by a great fault along the west border of the range, or more probably by a combination of the two. The details of the time and the stages of this sequence of events must wait for final solution until the geology of the east and west ranges is more intimately known. Interesting discussions of the orographic development of the Rocky Mountains, incidentally dealing with the history of the San Luis Valley region, have been given by S. F. Emmons and R. C. Hills (see bibliography, p. 8), to whose papers the reader is referred.

The first stage in the history of the valley of which any record is left in the formations of the area is the period when the deposition of the Santa Fe formation began. At this stage the depression consisted of a broad valley limited by the Sangre de Cristo and Culebra ranges on the east and probably extending considerably farther westward than the limits of the present valley. This depression opened to the south along the valley now occupied by the Rio Grande. In this depression in late Miocene time there was laid down the succession of sands, conglomerates, tuffs, andesites, and basalts which make up the Santa Fe formation. At the close of deposition the valley probably presented the appearance of a bolson valley sloping to the center from the height of the San Pedro Mesa, the Garland Mesas, and the great sand dunes on the east side of the valley, and from well up on the range on the west side of the valley. From vents around the west and south margins of the valley that had furnished the flows interbedded with the sands and conglomerates there was poured out on this plain a sheet of dark andesitic lava, which covered the deposits on the west side and over the whole south half of the valley but did not reach those on the east side of the valley north of Fort Garland. Succeeding this flow there was apparently a downwarping of the central valley, with faulting in a northeast-southwest direction in the vicinity of the northwest face of the San Luis Hills, the downthrow being to the northwest and carrying the top of the Santa Fe formation to a depth of more than 1,000 feet in the center of the valley. Accompanying or following these movements was an extrusion of the basaltic cones and table-top mountains which compose the San Luis Hills. Presumably at this time also occurred the extrusion of those masses which, as Los Mogotes Peak, Chiquita Peak, and other prominent points and cones on the west and south sides of the valley, rise above and apparently through the Santa Fe formation; though it is possible that these points mark as well the vents through

which have come some of the interbedded lavas of the Santa Fe formation.

In the depression caused by the down warping in the center of the valley there was formed an extensive fresh-water lake, in which was deposited the series of sands and clays that make up the Alamosa formation. On page 81 it is shown that this sedimentation was interrupted by arid periods, when the lake shrank to a small size, was more or less alkaline, and supported considerable vegetation, principally moss. These deposits of alkali and organic matter, covered by later beds of clay and sand, are the source of the gas and the color of the tinted waters of the Mosca-Hooper district (pp. 81–82).

So far as may be seen, no change in the attitude of the valley has ensued since the close of deposition of the Alamosa formation. When the trough of the valley had been filled with that series of sands and clays to the height of Hansen Bluff the overflow of the lake in which they were deposited had cut down the outlet through the San Luis Hills south of Los Sauces village nearly to the level of the bluff, and the drawing off of the lake followed. Further erosion has cut the outlet some 60 feet deeper and carried away that depth of the Alamosa formation along the Rio Grande adjacent to the bluff.

Nearly one hundred years ago Jacob Fowler, trapper and explorer, entered the San Luis Valley from the south. The following excerpt is the entry made in his journal [a] on the evening of his arrival in the valley. The lines italicized by the present writer show how clearly this observant trapper grasped the character and later geologic history of the valley:

monday 18th Feby 1822

We Sot out Early up the River and at about 12 miles Came to the upper Eand of the High Rocks and going down a gradual decent three or four Hundred yds Came to a low Bottom on the River the Bank being low not more than six or Eight [feet] High the River butifull and a bout one Hundred yds Wide—But all frosen up tite—We Heare got Watter for the Horses—it is Heare proper to Remark that the River as far as We Have Seen it pasing down betwen the High Rocks or mountains—dose not move in a very gentle manner as It appears much Impeded by the Rocks falling from Each Side, and is forsed forward dashing from one Rock over others In almost one Continued foam the Hole distance threw the mountains Which from What I Can larn is about seventy miles When it appeers below In an oppen Cuntry—*I Have no doubt but the River from the Head of those Rocks up for about one Hundred miles Has once been a lake of about from forty to fifty miles Wide and about two Hundred feet deep—and that the running and dashing of the Watter Has Woren a Way the Rocks So as to form the present Chanel*—We this day Crosed a dry Branch. But Have not Seen one Streem of Watter In all the distance We Have Came up on the [west] Side We traveld nor Cold our Horses get one drop of Watter in all that distance but the Eat Snow When the Cold get it.

Stevenson [b] was strongly of the belief that "the whole character here seems to admit of no inference other than that the valley is

[a] The journal of Jacob Fowler, 1821–22, edited by Elliott Coues, New York, 1898, pp. 112–114.
[b] Rept. U. S. Geog. Surveys W. 100th Mer., vol. 3, 1875, pp. 460, 462.

the result of glacial erosion. * * * It seems not impossible that the glacial mass was of equal extent (with the ancient lake) and that in its retreat it delayed for a time, its foot occupying the line marked by the abrupt wall forming the southern boundary of the present basin."

Endlich [a] rejected this view and maintained that the effects of glacial modification were restricted to the immediate edges of the valley, in which limitation the present writer fully concurs. It has been noted in the preceding pages that the valley glaciers in the eastern range reached only to the crests of the alluvial fans and that even in the larger streams of the west ranges they did not reach that far. If, with exceptionally favorable gathering grounds in the high Sangre de Cristo Range, the valley glaciers no more than reached the upper margin of the alluvial slope, it is not probable that a great glacier could gather in the valley.

Since the draining of the lake in which the Alamosa formation was deposited, sedimentation in the valley has been limited to the deposition of alluvium along the valley and of gravel veneering on the alluvial cones and slopes. On the whole, the amount of deposition since the glacial period seems to have been inconsiderable. The Zapato fan, where the discharge of the creek has been confined since glacial time to the north edge, has received no perceptible addition, but rather has been reduced by erosion.

The impression prevails locally that the Sangre de Cristo Range is younger than the mountains west of the valley. This impression has probably arisen from the notion that the level valley is a continuation of the Great Plains east of the Front Range of the Rocky Mountains and that the oceanic waters which deposited the plains formations washed the base of the western ranges until the Sangre de Cristo Range was upheaved and cut the valley off from the sea. Possibly the gentler outline and older aspect of the western ranges have contributed to the impression. It has been made plain in the preceding pages that the western ranges adjacent to the valley are, in part at least, composed of the youngest formation but one in the region, and that this was deposited long after the Sangre de Cristo was elevated. However, the depression of the Santa Fe formation in the center of the valley and certain warping in that formation northwest of Fort Garland may have been accompanied by a further elevation of the Sangre de Cristo Mountains. This possibility is strengthened by the attitude of the lava flows covering the Raton Mesa and others east and south of Trinidad. These flows, according to information communicated by Mr. W. T. Lee, spread over the beveled edges of formations ranging from Dakota to post-Laramie in age and are themselves of Tertiary age. They have been elevated

[a] Ann. Rept. U. S. Geol. and Geog. Survey Terr., 1875, p. 223.

slightly, tilted away from the Culebra Range, indicating a rise of that range, and later dissected. It is reasonable to suppose that the elevation of the range which accompanied the deformation of these Tertiary lavas on the east side was contemporaneous with the deformation of the Santa Fe formation on the west side of the range.

In conclusion, the essential harmony of the local history herein set forth with the general history of the West for the same time may be recapitulated: Miocene deposition, unconformable below, of a series of sands, gravels, and interbedded lavas and tuffs, followed by orographic movements and additional volcanic activity, succeeded by quiet deposition of sands and clays in fresh-water lakes, passing without stratigraphic break into Pleistocene and Recent deposits.

UNDERGROUND WATERS.

GENERAL CONSIDERATIONS.

PREREQUISITE FEATURES OF AN ARTESIAN SYSTEM.

The essentials of an artesian system are few and simple:

1. An inclined stratum, as of sand, which receives water in the higher portions and transmits it freely to the lower portions.

2. Relatively impervious layers, as clay or shale or finer sand, which confine the water within the water-bearing bed or aquifer.

3. Resistance to lateral escape of the water from the lower parts of the aquifer greater than its resistance to the ascent of water in the well. This may be due to either of several factors, among the commonest of which are—

(*a*) The bending up of the beds to form the opposite side of a basin.

(*b*) The thinning out of the water-bearing sand bed or aquifer.

(*c*) Loss of porosity in the aquifer.

(*d*) Frictional resistance to lateral movement within the aquifer itself.

(*e*) Unconformable depositional contact with less pervious beds, as along lower Conejos River.

APPLICATION TO THE SAN LUIS VALLEY.

The San Luis Valley is an almost ideal example of the artesian basin. The structure of the valley has been already discussed, and a cross section of the valley is shown in figure 3. The water occurs in beds of fine blue to gray sand varying from 1 to 20 feet or more in thickness, separated from one another by beds of blue clay ranging from 1 foot to several hundred feet in thickness. In the alluvial slope near the base of the mountains at the margin of the valley the clay beds thin out, the lowest ones usually reaching the farthest and highest up the slope, thus giving the greatest pressure to the flows beneath

them, where they are penetrated out in the valley. If all lower openings and avenues of escape in the aquifers were stopped, the water would rise to the level of the receiving area, or, rather, to the lowest point in that area. Thus the water in the strata penetrated at Alamosa would have sufficient head or be under sufficient pressure to rise as high as the margin of the basin about Monte Vista, which would be about 100 feet above the surface at Alamosa. As a matter of fact the head of the Bucher well at Alamosa, the deepest in that vicinity, is not over 56 feet, and the greater number of wells reaching a depth of about 700 feet have a head of less than 40 feet. This loss of head is partly due to the drain upon the water bed by other wells but is probably due chiefly to loss by lateral flow where the sands of the Alamosa formation come into contact with the Santa Fe formation along the northwest margin of the San Luis Hills. In support of this suggestion may be cited the fact that wells near the mouth of Conejos River, in the very lowest portion of the artesian basin, instead of having the very strongest pressure in the valley, as they theoretically should, have on the contrary but small pressures, though very good flows.

SOURCE OF THE ARTESIAN WATER.

The source of supply of the artesian water in the San Luis Valley is unquestionably the mountain streams which flow down across the alluvial slope. The disappearance of the mountain streams soon after they reach the alluvial slopes is a matter of common observation. This is particularly true of the streams flowing from the Sangre de Cristo Range. Very few of these streams get beyond the piñons which cover the upper part of the alluvial slope. The same is true of the streams on the west side of the valley, though the greater number of the streams there, being much longer and larger than any in the Sangre de Cristo Range, have sufficient volume of water to stand the loss in passing across the alluvial slope and to send a considerable flow to the Rio Grande, especially in the wet season. But all these streams suffer noticeable loss in the region of the gravel slope.

The largest stream entering from the west is, of course, the Rio Grande, and along this stream various discharge measurements have been made with a view to showing the loss by seepage of this river in various portions of its course through the valley. As shown by these gagings,[a] the actual loss by seepage of the Rio Grande between Del Norte and Monte Vista, a distance of 15 miles, is 75 second-feet. No other section of the river shows a loss at all comparable to this; in fact, the remainder of its course for the most part shows a gain from seepage. Discharge measurements of various other of the principal

[a] Bull. Colorado Agr. Coll. No. 48, p. 30.

streams on the west side of the valley have been made from time to time by the state engineer of Colorado, the results of which show like losses in the region of the alluvial slope.

ADEQUACY AND PERMANENCY OF SUPPLY.

It has been explained on a previous page that the artesian supply has the first call upon the water of the Rio Grande, inasmuch as one of the large ditches, which has the earliest priority of all, takes its water from the Rio Grande below the section which supplies water to the artesian basin. Since this priority must be satisfied before any water is taken out above, there will always be water flowing across the area which supplies the artesian basin when there is any water in the river at all. This is largely true of the other streams as well. Therefore the artesian basin will always be supplied with water, and any question of failure of wells in the valley will be one of mutual interference as a result of too great concentration of wells, and not one of expansion of the irrigation systems.

CAPACITY.

In 1891 Professor Carpenter, estimating 2,000 wells in the valley, with an assumed average flow of 25 gallons per minute, found the total artesian flow to be about 110 second-feet. At 70 acres to the second-foot, this volume of water, if all used, would irrigate 7,700 acres.

Since that year many new deep wells have been bored and older ones sunk to deeper and heavier flows, so that the average flow is now greater than at that time. By actual count, the wells shown on the map and plats herewith number 3,234. The average flow of 1,000 measured and estimated 2 and 3 inch wells, excluding those in towns, amounts to 40 gallons per minute. The wells of the towns have in general much smaller flows than those in the country, but it is believed that the large flows of the wells over 3 inches in diameter, which are not included in the average, will offset the small flows of the town wells, and that the average of 40 gallons is a fair one. Flowing at this average, the 3,234 wells in the valley will yield a volume of water equal to 286 second-feet. At the rate of 70 acres to the second-foot this volume of water will irrigate 20,000 acres. This estimate of the duty of water is probably a minimum. On the average it is perhaps 25 per cent too small, so that 25,000 acres is nearer a true estimate. With adequate storage, this volume of water could be made to irrigate two or three times as great an acreage.

It is practically impossible to estimate the acreage actually irrigated from artesian wells unless a painstaking census be made with that object in view. Even so, it would be impossible to get accurate figures, inasmuch as many persons use the flow of the wells

in connection with the ditch water. In the absence of such actual figures of acreage irrigated from artesian water, some estimate, such as has been made of the possible irrigation from artesian water, must serve. The only wells not used at all in irrigation, a small percentage of all the wells of the valley, are those used for stock purposes. They are scattered here and there over the untilled land, and the water from them usually sinks within a short distance of the well. The larger wells are almost without exception used for purposes of irrigation. In 1904 there were in the valley 76 6-inch wells, with an average flow of over 300 gallons a minute, and 77 wells over 3 inches and under 6 inches in diameter, with an average flow of about 175 gallons a minute. The total flow of these larger wells was approximately 80 second-feet.

However, the true value of artesian water for irrigation purposes is not to be reckoned by the flat acreage it is capable of irrigating. The special value of artesian water lies in the steady, unfailing supply in times of drought when ditch water is wanting.

FLOWING WELLS.

MARGINAL REGION.

ALAMOSA AND VICINITY.

This district includes the wells in the town of Alamosa and those southeastward along the Rio Grande for several miles, as well as those north and east of the town, within a radius of 6 or 7 miles. The district contains some of the largest and most of the deep wells in the valley. Within the town itself, covering 1 square mile (Pl. IX), there are 140 wells, the greater number of which are about 700 feet deep or within 50 feet more or less than that depth.

The Bucher well, on the other side of the Rio Grande from Alamosa but in the northeast corner of the same section, is one of the oldest as well as one of the deepest wells in the valley. This well, sunk in 1889, is nearly 1,000 feet deep. The main flow was secured at a depth of 932 feet and the smaller flow at 500 feet, the combined flow in 1891 being reported by Professor Carpenter to be about 600 gallons a minute, or $1\frac{1}{3}$ second-feet. The diameter of the well is 6 inches at the bottom. Reduced to 3 inches, it throws a jet of water 48 inches high. The temperature is 74.7°[a], according to Professor Carpenter, who reports that the pressure indicates a head of 56 feet. No record was kept of the geologic section of the well. Analyses of the water are given in the table of analyses on page 112. The water is without taste, like that of shallower flows. It is caught in a large reservoir and used in a small way for irrigation. A view of this well is shown in Plate VII, *A*.

[a] All temperatures here given are expressed in degrees Fahrenheit.

The town well, situated in the northwest corner of Alamosa, a mile west of the Bucher well, is 865 feet deep and 6 inches in diameter and is cased to a depth of 852 feet. The flow in 1891, as measured by Professor Carpenter, was 400 gallons a minute. The temperature is 72° F. The water from this well, with additions from the various private wells, is carried in ditches through the streets of the town, irrigating the shade trees and grass plats along the way. The following is a condensed record of the well:

Record of Alamosa town well.

	Thickness.	Depth.
Recent:	*Feet.*	*Feet.*
Alluvial soil	3	3
Sand	10	13
Alamosa formation:		
Blue clay	511	524
Black sand (flow)	2	526
Blue clay	324	850
Black sand (strong flow)	15	865

The Denver and Rio Grande Railroad well at the water tank is 938 feet deep and 4 inches in diameter at the bottom. It has a flow of 60 gallons a minute at the surface of the ground, or 20 gallons a minute where it empties into the tank at a height of 37 feet above the ground. The pressure, when finished, indicated a head of 46 feet. A small flow was struck at 630 feet, and at 838 feet a flow of 90 gallons a minute, the pressure of which indicated a head of 32 feet. The purpose of going on to the deeper though smaller flow was to get sufficient head to lift the water into the top of the water tank at 37 feet. The flow at 937 feet is the same flow that is struck by the Bucher well. These two are the only wells having this flow in the vicinity of Alamosa, though there are a few other wells deep enough to reach it. The log of the well is as follows:

Record of Denver and Rio Grande Railroad well.

	Thickness.	Depth.
Recent:	*Feet.*	*Feet.*
Soil	3	3
Sand	15	18
Alamosa formation:		
Clay	3	21
Sand	9	30
Clay	18	48
Sand	6	54
Light clay with streaks of sand	296	350
Blue clay with some sand strata	280	630
Sand (small flow)	2	632
Clay with some sand strata	206	838
Sand (strong flow)	10	848
Hard clay	72	920
Sand (flow)	2	922
Hard clay	13	935
Hard layer	2	937
Sand and gravel (strong flow).		

PLAT OF ALAMOSA, SHOWING LOCATION OF WELLS.

The Goodall well, 400 feet southeast of the Bucher well, is reported to have this section:

Record of Goodall well.

	Thickness.	Depth.
	Feet.	*Feet.*
Recent: Surface gravel and sand	40	40
Alamosa formation:		
Yellow clay	15	55
Black sand	1	56
Blue clay	204	260
Black sand (first flow, light)	1	261
Blue clay	245	506
Black sand (second flow, light)	1	507
Blue clay	109	616
Black sand (third flow, light)	1	617
Blue clay	159	776
Red sand (fourth flow, good)	10	786
Blue clay	90	876
Red sand and small gravel (fifth flow, good)	7	883

This well is 3 inches in diameter and the temperature is 70°. The flow is the large one struck in the town well and at 838 feet in the Denver and Rio Grande Railroad well at the water tank.

The Spriesterbach well, in the northern part of Alamosa, 725 feet deep and 3 inches in diameter, has a temperature of 66°. The well has recently failed considerably. It seems likely, as indicated by the temperature, that the water is coming from a flow somewhat above the bottom. The detailed geologic section of this well has been given on page 41. Analysis shows the water to contain 295 parts per million total solids.

The Hirst well, in the southern part of Alamosa, is 4 inches in diameter, 820 feet in depth, and cased to bottom. The following flows are reported:

First flow, 220 feet, stream size of lead pencil.
Second flow, 475 feet, stream 1 inch in diameter.
Third flow, 680 feet, good flow.
Fourth flow, 800 feet, heavy flow in 8–10 feet red sand.

The Alamosa Milling and Elevator Company's well is 4 inches in diameter and 680 feet deep, cased to the bottom. The temperature of this well is 69° and that of a deeper 3-inch well is 72°. An analysis of the water will be found in the table of analyses, page 112.

At the electric-light plant there is a well cased 6 inches for some distance and 4 inches to the bottom at 800+ feet. The temperature is 73°.

The Fritz Emperius well is a mile and a half southeast of Alamosa, in the NW. ¼ sec. 13, T. 37 N., R. 10 E. The depth is 810 feet, cased to the bottom, and the diameter is 4½ inches. The temperature is 72° and the flow forms a jet 7½ inches above the casing. The flow is estimated to be about 350 gallons a minute and, stored in a reservoir, will irrigate 50 acres. The cost was $950.

The Wilkins well, a mile southeast of Alamosa, in the SE. ¼ sec. 14, T. 37 N., R. 10 E., is 800 feet deep, cased to the bottom, and is 5½ inches in diameter. It is reported to have a flow rising 7 inches above the casing. The temperature is 72°.

Three miles down the Rio Grande from Alamosa, on the Wilkins, Schwartz, and Worcester ranches, there are several 4, 4½, and 5 inch wells that have good flows.

At the Blanca farm, 4 miles north of Alamosa, in the southeast corner of the NE. ¼ sec. 21, T. 38 N., R. 10 E., there is a 3-inch well, 840 feet deep, cased to the bottom. The flow, struck in gravel, throws a jet 6½ inches above the casing, and is estimated to be 130 gallons per minute. The temperature is 72° and there is a slight taste of sulphur. The analysis of the water is given in the table on page 112.

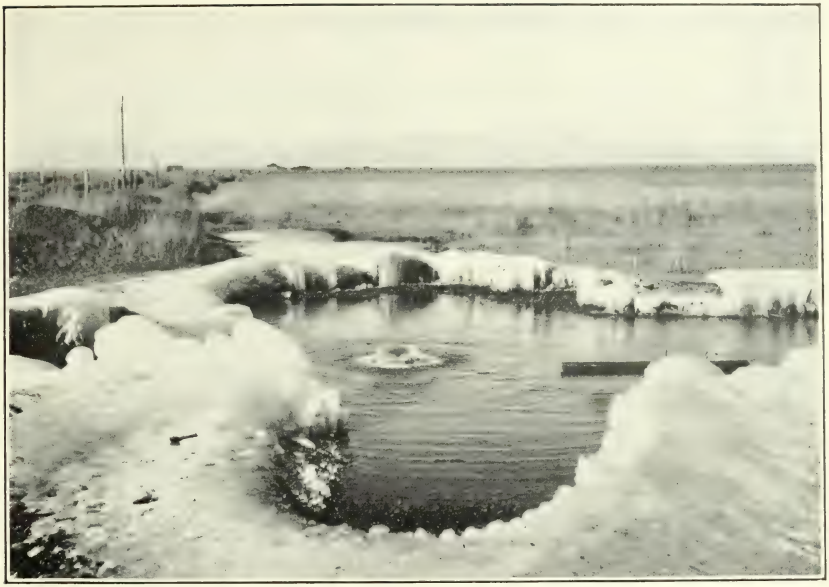
On George Newsom's ranch, 5 miles northeast of Alamosa, in the SW. ¼ sec. 33, T. 38 N., R. 11 E., there are eight 3-inch wells, two 4-inch wells, and one 6-inch well, all with fair flows. The geologic section, which is typical for this vicinity, is as follows:

Section of Newsom wells.

	Thickness.	Depth.
	Ft. in.	*Feet.*
Recent:		
Soil and clay	16	16
Gravel and sand (cased to this level)	10	26
Alamosa formation:		
Clay	74	100
Sand (first flow)	4	100
Clay	25	125
Sand (second flow)	5	126
Clay	34	160
Sand (third flow)	1	161
Clay	64	225
Sand (fourth flow)	1 4	226
Clay	124	350
Sand (fifth flow)	2	352
Clay	48	400
Sand (sixth flow)	4	404

HENRY STATION AND VICINITY.

This district is characterized by the greatest number of wells of large bore in the valley. The number of 6-inch wells in this vicinity and westward in the Fountain neighborhood is over 50, and in addition there are several 4-inch and 5-inch wells. All these larger wells have been put down for purposes of irrigation, many of them recently. Twelve of these have been recently put down on the Empire farm of the Southern Colorado Land Company, in the immediate vicinity of Henry station. The following section of one of these is typical of the region:



A. SIX-INCH WELL ON EMPIRE FARM.

B. KINCH WELL.

Section of Empire farm well.

	Thickness.	Depth.
	Feet.	*Feet.*
Recent: Surface gravel and loam	11	11
Alamosa formation:		
Clay	69	80
Sand (small flow)	½	80½
Clay	59½	140
Sand (flow)	2	142
Clay	38	180
Sand (flow)	3	183
Clay	57	240
Sand (flow)	3	243
Clay with various beds of sand	194	437
Sand (flow)	3	440
Clay	40	480
Gravel below ("gravel" flow, strong).		

Another well on the same farm, by a different driller, gives this record:

Section of Empire farm well.

	Thickness.	Depth.
	Feet.	*Feet.*
Recent: Gravel	17	17
Alamosa formation:		
Clay	53	70
Sand (first flow)	1	71
Clay	54	125
Sand (second flow)	1	126
Clay with water-bearing sand beds every 20 feet	324	450
Gravel (gravel flow)	3	453
Clay	50–90	500–545
Bowlders below (strong flow).		

This bowlder bed is reached at a depth of 500 feet on the west side of the ranch, and at a depth of 545 feet on the east side. A typical view of one of these wells in winter is shown in Plate X, *A*. The casing is cut off close to the ground so that the water will not dig out a great hole around the well, as it would if the casing extended far above the ground.

Two 6-inch wells on the Mitchell ranch, in the SE. ¼ sec. 33, T. 37 N., R. 10 E., have depths of 540 and 575 feet. Each throws a 3-inch jet and together the flow is 1⅝ second-feet, irrigating 100 acres. They are cased only to the first clay and the total cost of both was $233.

A well on the Adams ranch, 3 miles due east of Henry station, in the southeast corner of the SW. ¼ sec. 35, T. 37 N., R. 10 E., furnishes the following section:

Section of Adams well.

	Thickness.	Depth.
	Feet.	*Feet.*
Recent: Surface gravel and loam	20	20
Alamosa formation:		
Clay	40	60
Sand	1	61
Clay, with water-bearing sand beds 2 feet or so in thickness about every 40 feet	619	680
Gravel below (heavy flow).		

This well, 6 inches in diameter, bored in November, 1892, is reported to have had originally a jet 9 inches high. By 1904 the jet was reduced to 3½ inches.

On the J. W. Kinch place, in the NE. ¼ sec. 9, T. 36 N., R. 9 E., a 6-inch well, when new, had a jet of 12 inches, which is now reduced to 5½ inches. A section of this well is as follows:

Section of Kinch well.

	Thickness.	Depth.
	Feet.	*Feet.*
Recent: Surface gravel and loam	14	14
Alamosa formation:		
Clay	66	80
Black sand (first flow)	1	81
Clay	44	125
Sand (second flow)	2	127
Clay, with water-bearing sand beds 2 to 4 feet thick every 40 or 50 feet	260	387
Gravel and coarse sand (gravel flow)	15	402

This well is shown in Plate X, *B*.

FOUNTAIN NEIGHBORHOOD.

In the SE. ¼ sec. 16, T. 37 N., R. 9 E., on the place owned by George Ottaway, there are two 6-inch wells, dug in 1900 and 1901. The south well, 585 feet deep, has this section:

Section of Ottaway well.

	Thickness.	Depth.
	Feet.	*Feet.*
Recent: Surface clay and gravel	14	14
Alamosa formation:		
Blue clay	106	120
Sand (first flow, very weak)	1	121
Blue clay	189	310
Sand (fair flow; 4 feet head)	2	312
Blue clay	40	352
Sand (flow)	2	354
Blue clay	40	394
Sand (flow)	2	396
Blue clay	100	496
Sand (flow)	2	498
Blue clay	38	536
Sand (flow)	2	538
Blue clay	17	555
Hard yellow clay	20	575
Gravel (gravel flow)	10	585

These wells are reported to have had jets of 5½ inches when first put down, but they are now reduced to 2 inches. The temperature is 64° and the two wells irrigate 160 acres.

When wells are sunk to the gravel flow in this vicinity the water runs out at the top of the drill rods 22 feet above the surface of the ground, showing a head of that much or more.

The well on the Hubbard place, in the southwest corner of the NE. ¼ sec. 9, T. 37 N., R. 9 E., has the following section:

Record of Hubbard well.

	Thickness.	Depth.
	Feet.	*Feet.*
Recent: Surface clay and gravel	16	16
Alamosa formation:		
White clay	44	60
Blue clay	80	140
Hard streak	1	411
Sand (first flow)	1	142
Soft mud	24	166
Sand (second flow)	1	167
Blue clay	34	201
Sand (third flow)	1	202
Blue clay	119	321
Red sand (fourth flow; heavy)	1½	322½
Blue clay	42½	365
Sand (fifth flow)	2	367
Blue clay	63	430
Sand (sixth flow)	2	432
Blue clay	8	440
Sand (seventh flow)	2	442
Hardpan	3	445
Blue clay	35	480
Gravel (eighth flow; gravel flow)	2	482

This vicinity was one of the earliest in which artesian wells were sunk for irrigation on an extensive scale, and now over 2,000 acres are irrigated from wells alone, besides which much artesian water is turned into the ditches and used in conjunction with the ditch water.

LA JARA AND VICINITY.

The wells of the La Jara district are of moderate depth and very strong flow. In the town itself there are 71 wells, the distribution of which is shown in figure 5. These range in depth from 65 to more than 300 feet. The following section is reported to be typical:

Section of well at La Jara.

	Thickness.	Depth.
	Feet.	*Feet.*
Recent: Soil and gravel	30	30
Alamosa formation:		
Blue clay	15	45
Black sand (first flow)	1	46
Blue clay	19	65
Black sand (second flow)	3	68
Blue clay	17	85
Red sand (third flow)	2	87
Blue clay	16	103
Red sand (fourth flow)	2	105
Blue clay	15	120
Red sand (fifth flow)	2	122
Blue clay	10	132
Red sand (sixth flow)	2	134
Blue clay	11	145
Red sand (seventh flow)	1	146
Blue clay	14	160
Red sand (heavy flow)	3	163
Blue clay	17	180
Red sand (ninth flow)	3	183
Blue clay	10	193
Red sand (tenth flow)	3	196
Blue clay	3	199
Gravel (eleventh flow)	17	216
Clay	12	228
Sand (twelfth flow)	5	233

The ninth flow has a head of 12 feet, which formerly was 16 or 18 feet; the tenth flow has a head of 15 feet.

The well of the La Jara Milling and Elevator Company has a depth of 308 feet, a diameter of 4½ inches, and a temperature of 48°. An analysis of the water from this well may be found in the table of analyses, page 112.

The well at the residence of L. A. Norland is 4½ inches in diameter and 325 feet in depth, cased to 300 feet. The temperature is 49½°.

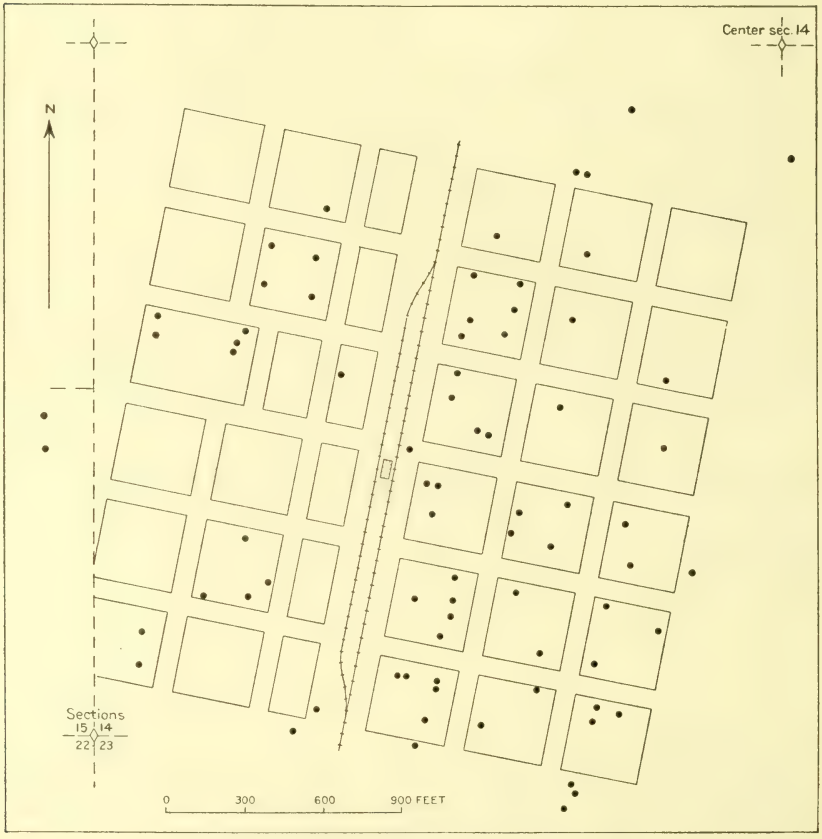


FIGURE 5.—Plat of La Jara, showing location of wells.

Reduced to 3 inches it throws a jet 18 inches high; reduced to 2 inches it throws a jet 7 feet high. The jet for the full aperture of the well is about 3 inches.

On the ranch of William Lambert, 1 mile north and 1 mile west of La Jara, a well 210 feet in depth gives this section:

Section of Lambert well.

	Thickness.	Depth.
	Feet.	*Feet.*
Recent: Gravel and sand	18	18
Alamosa formation:		
Clay	109	127
Sand (first flow)	1	128
Clay	19	147
Sand (second flow)	1	148
Clay	39	187
Sand (third flow)	1	188
Clay	22	210
Solid rock below.		

This well is not included in the series extending eastward from Capulin, as described on page 95, because the water was struck in the water-bearing beds of the basin and not in the lava, as in those wells. Furthermore, it is possible, though not probable,

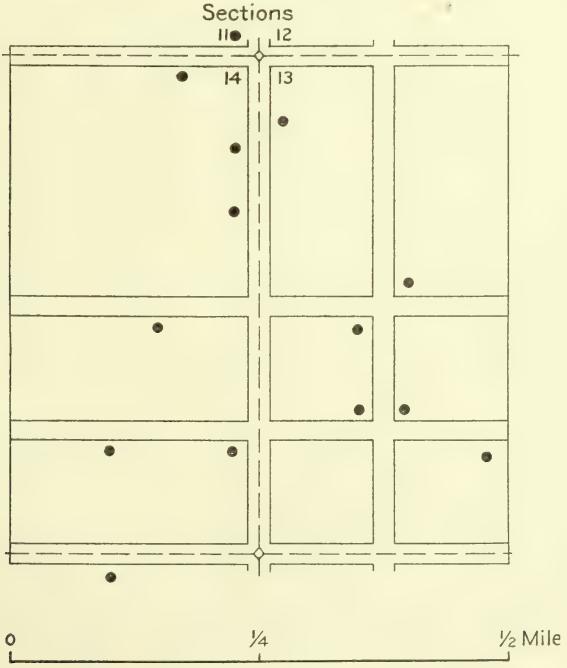


FIGURE 6.—Plat of Richfield, showing location of wells.

that the rock struck in this particular well may have been a large bowlder.

The plat of the village of Richfield (fig. 6), half a mile northeast of La Jara, shows the location and number of wells in that place.

SANFORD AND VICINITY.

A plat of the town of Sanford, which covers 1½ sections, is shown in figure 7. The blocks are 220 yards from street to street, and each block in the more closely settled portions of the town contains from one to four wells. Most of these are shallow, ranging in depth from

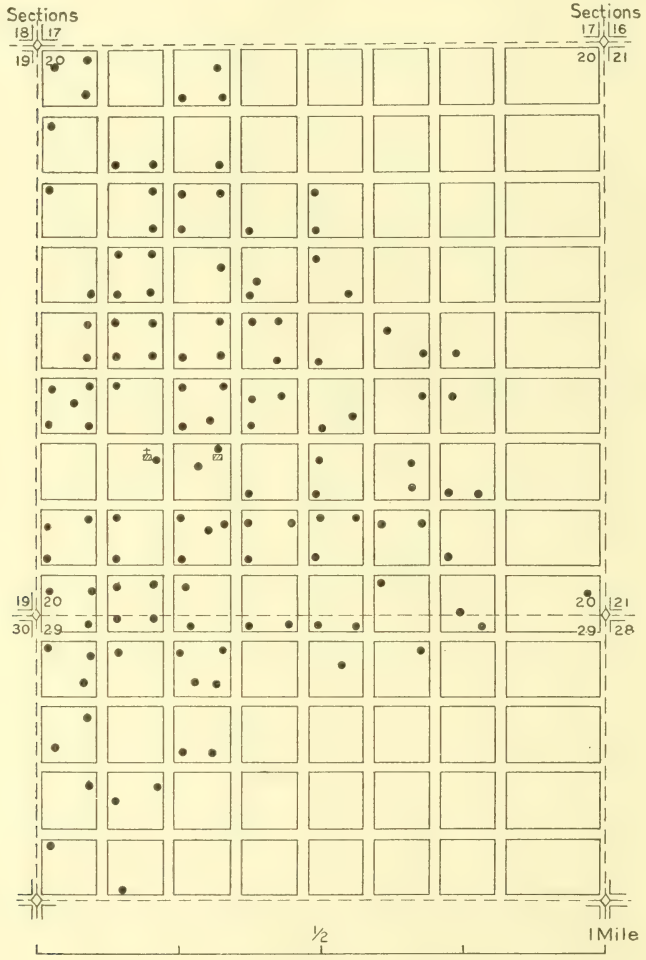


FIGURE 7.—Plat of Sanford, showing location of wells.

70 to 200 feet, and nearly all are 2 inches in diameter. Many wells which formerly obtained the first flow at 70 feet have since had to be sunk deeper, owing to the exhaustion of the first flow by mutual interference of the wells, which number 126 in the village. The following section is given as typical of these wells:

Characteristic well section at Sanford.

	Thickness.	Depth.
Recent:	*Feet.*	*Feet.*
Soil and gravel	22	22
Sand	12	34
Alamosa formation:		
Blue clay	36	70
Black sand (first flow)	2	72
Blue clay	23	95
Red sand (second flow)	2	97
Blue clay	13	110
Red sand (third flow)	2	112
Blue clay	11	123
Red sand (fourth flow)	3	126
Blue clay	19	145
Red sand (fifth flow)	1	146
Blue clay	19	165
Red sand (sixth flow)	1	166
Blue clay	19	185
Red sand (seventh flow)	2	187

VICINITY OF LOS SAUCES.

The little Mexican plaza, Los Sauces, lies a mile or so south of the artesian limit, but a number of wells on the Atkinson, Austin, Stewart, Myers, Becker, and Hansen ranches lie nearer to Los Sauces than to any other post-office in the valley.

On the Peter Hansen ranch there are a number of 2 and 3 inch wells which have good flows. The depth ranges from 200 to 300 feet, and the water has a temperature of 53° to 55°.

On Fritz Becker's ranch a well in the NE. ¼ sec. 15, T. 36 N., R. 11 E., flows about 26 gallons a minute. It has the following section:

Section of Becker well.

	Thickness.	Depth.
Alamosa formation:	*Feet.*	*Feet.*
Sand and clay	39	39
Hard streak	1	40
Sand (flow)	1	41
Clay with hard streaks	127	168
Sand (flow)	1	169

On W. H. Myers's lower ranch on Trinchera Creek, 4 miles above the mouth of the creek, near the eastern limit of flowing wells, six wells have been sunk which have yielded small flows. One of these near the house, 300 feet deep, had the following section:

Section of Myers well.

	Thickness.	Depth.
Recent:	*Feet.*	*Feet.*
Soil and sand	16	16
Gravel	2	18
Alamosa formation:		
Clay	40	58
Clay and sand	82	140
Fine gravel (small flow)	5	145
Clay and sand (no further flow)	155	300

On the Stewart ranch, opposite the mouth of Trinchera Creek, several 3-inch wells, 170 to 300 feet deep, have good flows and are utilized in irrigating hay land.

On the Austin ranch, at the mouth of the Conejos, are a number of 2, 3, and 4 inch wells which have unexpectedly small flows, considering that they are at the very lowest point in the artesian basin. It has been already shown that this small flow is in all probability due to the escape of the water from the artesian water beds into the gravel beds of the Santa Fe formation.

On the Atkinson ranch, in the NW. $\frac{1}{4}$ sec. 9, T. 35 N., R. 11 E., there are several 2-inch wells from 125 to 140 feet deep. Three of these wells were sunk at a total cost, exclusive of casing, of $35. One of them has a flow of 65 gallons. The first flow, a small one, was reached at a depth of 33 feet.

PARMA AND VICINITY.

The big well on the Parma Land Company's farm, in the southeast corner of sec. 14, T. 38 N., R. 8 E., a mile west of Parma station, has the following section:

Section of Parma Land Company's well.

	Thickness.	Depth.
Recent:	*Feet.*	*Feet.*
Soil	3	3
Coarse gravel	32	35
Fine gravel	5	40
Sand	10	50
Alamosa formation:		
Blue clay	20	70
Sand	2	72
Clay	73	145
Fine sand (first flow, weak)	3	148
Clay	17	165
Sand	1	166
Clay	8	174
Coarse sand and gravel	4	178
Clay	8	186
Gravel	2	188
Clay	8	196
Sand (flow)	1	197
Clay	23	220
Sand (small flow)	1	221
Clay	30	251
Sand	1	252
Clay	16	268
Sand (small flow)	1	269
Clay	31	300
Sand and clay	4	304
Clay	18	322
Sand (fair flow)	3	325
Clay	68	393
Sand (fair flow)	2	395
Clay	26	421
Sand (good flow)	4	425
Clay, with some dry sand	47	472
Sand (heavy flow)	4	476

This well is 6 inches in diameter and the flow rises about $1\frac{1}{2}$ inches above the casing.

A well in the northeast corner of sec. 34, on the same ranch and in the same township as the well just described, obtained flows at depths of 140, 225, 275, and 324 feet.

A well at the residence of J. B. Outcault, in the southwest corner of the SE. ¼ sec. 7, T. 38 N., R. 9 E., has flows at 180, 225, 250, 280, and 300 feet.

A well in the northwest corner of sec. 17, one-half mile due east of the Outcault well, struck big flows also at 400 and 550 feet. All told, this well is reported to have had about ten different flows. When new it had a jet 8 inches high, which is now reduced to 2½ inches.

At H. H. Johansen's ranch, in the NW. ¼ SW. ¼ sec. 24, T. 38 N., R. 9 E., there are two wells with good flows. The larger well, in the reservoir south of the house, is 813 feet deep and is cased throughout. The diameter is 3 inches and the flow rises 4 inches over the casing, indicating a flow of more than 100 gallons a minute. Flows were struck at 250, 500, 600, 760, and 813 feet. At the bottom rock was struck which could not be penetrated in half a day's drilling.

MONTE VISTA AND VICINITY.

A plat of the town of Monte Vista is shown in figure 8. The wells in Monte Vista are more closely crowded than in any other town in the valley, there being 225 in the town and the immediate environs. These are for the most part 2-inch wells, ranging in depth from 115 to 300 feet. Many wells originally sunk to the first flow at 110 feet have been sunk deeper to secure a better flow. At first, here as elsewhere in the valley, wells were cased into the first bed of clay a short distance. Through the caving in of numbers of these wells, there has been such an interchange and mingling of water between the different flows that toward the center of the town, in the region of greatest crowding of the wells, there has resulted a uniformity of flow and a uniformity of temperature as well. In this territory wells yield a flow of about 2 gallons per minute, and have a temperature of 49°, whether the well be 130 or 300 feet deep. Around the borders of the town, particularly at the eastern border, wells have normal flows and temperatures.

The largest well in Monte Vista is that at the Monte Vista Milling Company's plant, sunk in 1897. This well is 302 feet deep. It is cased for 106 feet with 6-inch casing, for 160 feet with 4½-inch casing, and for 302 feet with 3-inch casing. A section of the well is as follows:

Section of Monte Vista Milling Company's well.

	Thickness.	Depth.
Recent:	*Feet.*	*Feet*
Soil and gravelly loam	10	10
Gravel and sand	50	60
Alamosa formation:		
Clay	40	100
Sand (first flow)	9	109
Sand and gravel, with various flows. Coarse gravel below (strong flow).	193	302

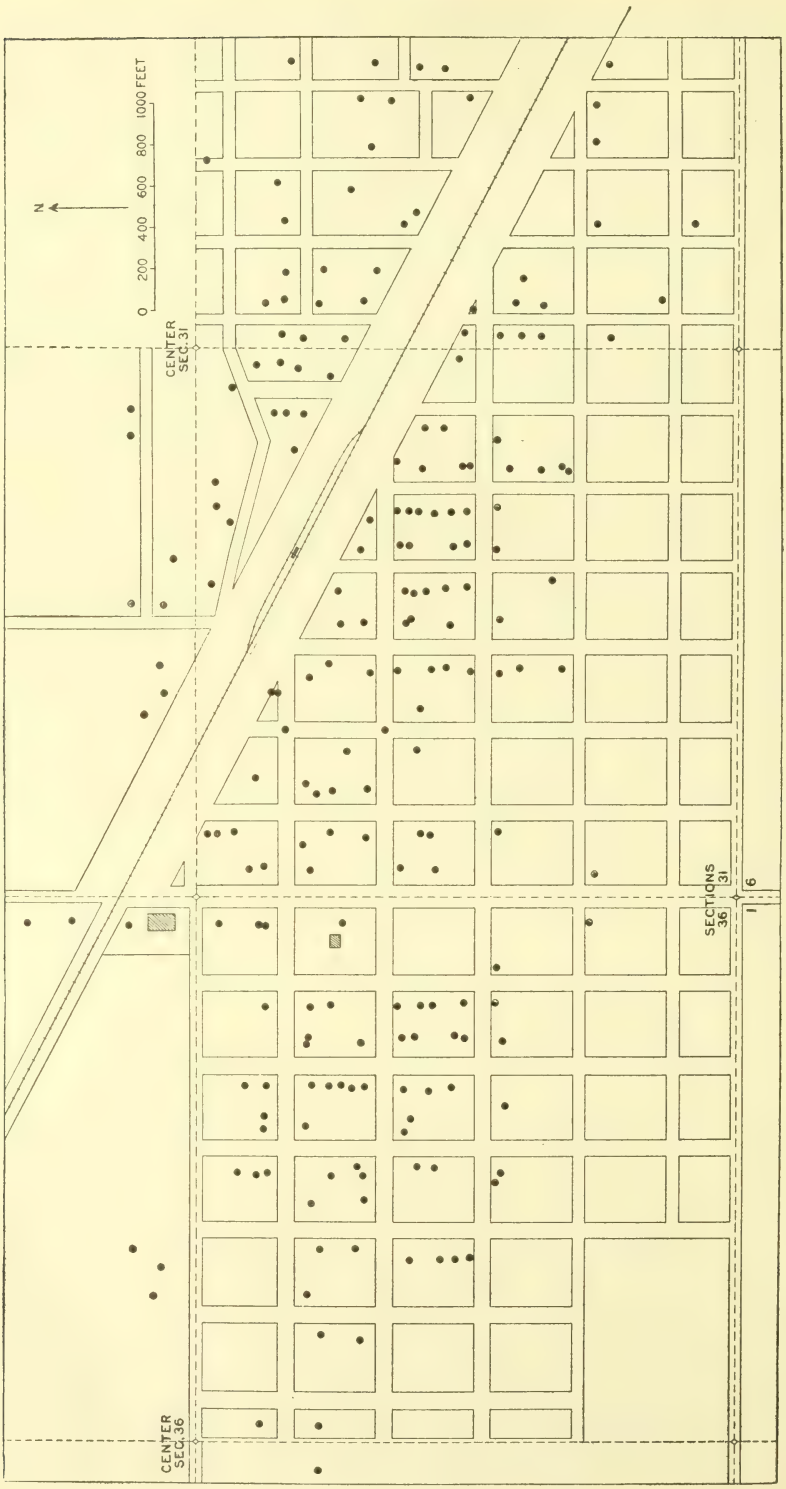


FIGURE 8.—Plat of Monte Vista, showing location of wells.

The well has a pressure of about 5 pounds and a temperature of 49° and flows 400 gallons a minute. An analysis of the water will be found in the table of analyses on page 112.

A section reported as typical for the wells in town is as follows:

Typical section of wells in Monte Vista.

	Thickness.	Depth.
	Feet.	*Feet.*
Recent: Soil and gravel	50	50
Alamosa formation:		
Clay	1	51
Quicksand	10	61
Blue clay	50	111
Dark sand (first flow)	9	120
Blue clay	8	128
Dark sand (second flow)	6	134
Blue clay	10	144
Black sand (third flow)	4	148
Blue clay	10	158
Black sand (fourth flow)	3	161
Yellow clay	14	175
Yellow sand (fifth flow)	2	177
Yellow clay	20	197
Yellow sand (sixth flow)	4	201
Yellow clay, with water-bearing beds of sand 2 feet thick at intervals of 10 to 20 feet.	99	300
Bowlders below.		

All wells on the east side of town show more clay and less sand and gravel. The head of the first well sunk in Monte Vista is reported to have been 12 to 14 feet. By 1889, according to Professor Carpenter, it had fallen to 7 feet. In 1890, when the number of wells in Monte Vista was 88, it had fallen to 4 feet. In 1904 some of the deeper wells in town still had a head of 7 feet, and the mill well, as noted, has a head of about 11 feet.

Four miles south of Monte Vista, in the valley of Rock Creek, the wells are very close together. The valley of Rock Creek is largely given over to meadows of native hay, and the wells are designed to irrigate the higher portions of these meadows out of the reach of the ditch water. With few exceptions these wells are 2 inches in diameter, as are also the wells in the town of Monte Vista. North and northeast of Monte Vista, across the Rio Grande, in T. 39 N., R. 8 E., practically every quarter section has a 2-inch well for domestic use. This township is well supplied with ditch water and no wells have been bored for irrigation exclusively. The wells in the Monte Vista district, outside of the town itself, all have excellent flows, ranging from 6 or 8 gallons up to 30 gallons a minute.

CENTER AND VICINITY.

The village of Center is situated in the midst of the grain belt of the valley, in a region well supplied with ditch water, and the wells are almost exclusively bored for domestic purposes. They are ordinarily 2 inches in diameter, and a fine flow is reached at about 200 to

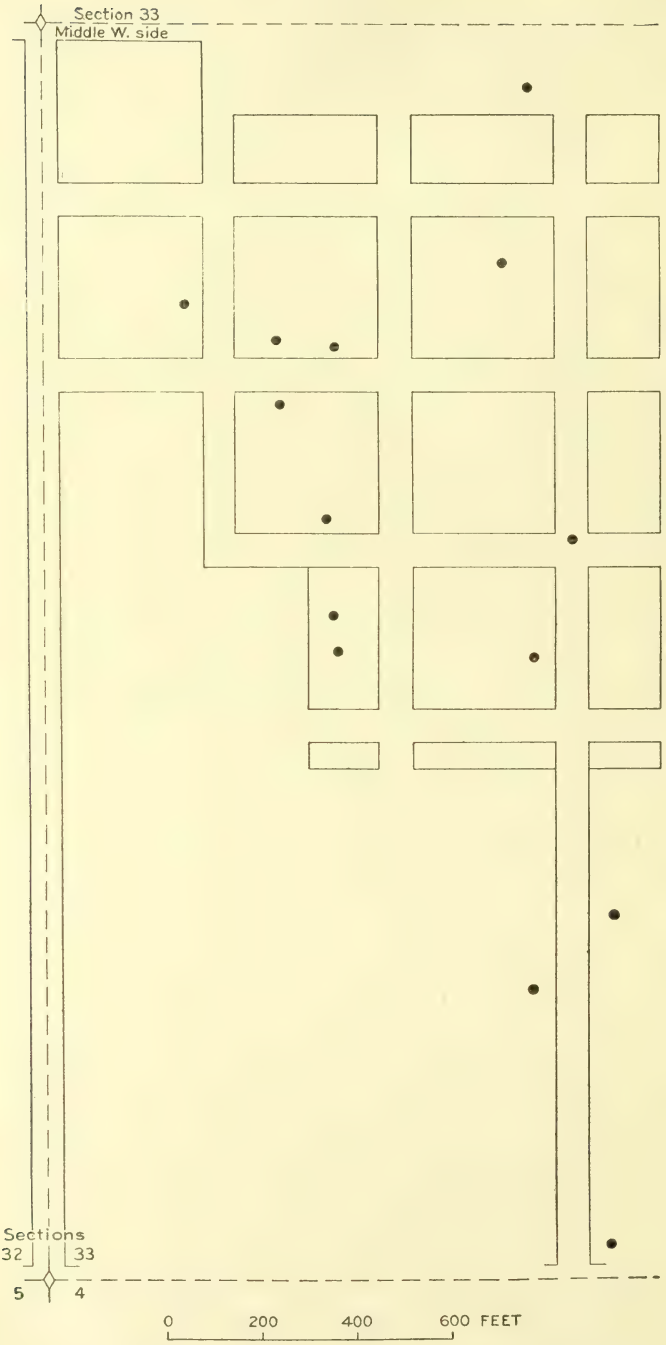


FIGURE 9.—Plat of Center, showing location of wells.

225 feet. The plat (fig. 9) shows the number and location of the wells in the village. The following section is given as characteristic for wells in the immediate vicinity of the village:

Characteristic section of wells in vicinity of Center.

	Thickness.	Depth.
	Feet.	*Feet.*
Recent: Soil and gravel	60	60
Alamosa formation:		
Clay and sand	95	155
Sand (small flow, with some sulphur)	1	156
Clay	10	166
Sand (second flow)	2	168
Clay	12	180
Sand (third flow)	4	184
Clay	12	196
Sand (fourth flow)	4	200

These flows farther east are found at somewhat greater depths, averaging 10 feet deeper to the mile.

A well in the SE. ¼ sec. 30, T. 40 N., R. 8 E., 5 miles west of south of Center, near the margin of the flowing-well area, is 464 feet deep. The first 200 feet was sand and gravel, with a little clay at the bottom, beneath which was obtained the first flow. Thence to the bottom of the well the formation was sand and gravel with some very thin beds of clay at intervals, but no further flow was found.

LOCKETT AND VICINITY.

The well on the John D. Hess place, in the southwest corner of the NW. ¼ sec. 26, T. 41 N., R. 9 E., is reported to have the following section:

Section of Hess well.

	Thickness.	Depth.
	Feet.	*Feet.*
Recent: Surface soil and gravel	100	100
Alamosa formation:		
Blue clay	120	220
Blue clay with streaks of sand	160	380
Sand	1	381
Light-blue clay	80	461
Sand (flow with 4-inch jet)	2	463
Streaks of clay and sand	94	557
Light-blue clay	150	707
Sand (flow with 7-inch jet)	3	710
Light-blue clay	58	768
Sand (small flow)	1	769

The well has a diameter of 3 inches and is cased for 478 feet. The flow is estimated at 135 gallons a minute.

Two miles west of south of the Hess well, in the NE. ¼ sec. 3, T. 41 N., R. 9 E., on H. J. Johnston's place, a well 800 feet deep has the following section:

Section of Johnston well.

	Thickness.	Depth.
	Feet.	*Feet.*
Recent: Surface gravel and sand	70	7
Alamosa formation:		
Blue clay	390	460
Sand (first flow)	2	462
Blue clay, with streaks of sand (flows every 15 to 30 feet)	138	600
Sand (big flow)	10	610
Clay, with a few small streaks of sand (some small flows)	190	800
Coarse gravel (good flow)	5	805

The temperature of this well is 63°. The flow is about 150 gallons a minute. The water is caught in a reservoir and used for irrigation.

VETERAN NEIGHBORHOOD.

The territory about Veteran schoolhouse, between Veteran and Carnero post-office, is one in which ditch water is likely to fail in a dry year, and this has led to the extensive development of artesian wells. This fact is brought out on the map by the close alignment of the wells along the west side of the farms. The strongest flows in the valley, considering the depth, are to be found in this neighborhood.

One of the largest wells is the Espinosa well in the NW. ¼ sec. 7, T. 42 N., R. 8 E. This well is 3 inches in diameter, 265 feet deep, and cased to the bottom. It throws a jet 25 inches above the top of the casing, equivalent to a flow of over 250 gallons a minute. In 1891 it had a jet 33¾ inches high, as recorded by Professor Carpenter, who reports that it is said to have had originally a jet 41 inches high. The temperature of this well is 54°. A view of the well is shown in Plate XI, *A*.

A half mile north, on the Navin ranch, in the southwest corner of sec. 1, T. 42 N., R. 8 E., two 3-inch wells, 383 feet deep, and cased for 83 feet, have jets 10 and 27 inches high, the well with the higher jet having been recently put down. The pressure of the older well as shown by gage indicates a head of 24 feet. The temperature is 55°. The combined flow of the two wells is very nearly 1 second-foot. The first flow was struck at 60 feet, the second at 120, and the third at 335 feet. A view of the newer well is shown in Plate XI, *B*.

Two miles northeast of Veteran schoolhouse, in the southwest corner of the SE. ¼ sec. 31, T. 43 N., R. 8 E., the Woodhouse well, 2 inches in diameter, has a jet of 13 inches. In this well a species of algæ had grown in such a manner as to constrict the opening and cause the water to jet to a height of 4 feet.

Practically all the wells in this region have excellent flows, but up the rise toward Carnero post-office the flows are smaller and smaller to the limit of the flowing wells.

A. ESPINOSA WELL, BORED IN 1888.

B. NAVIN WELL, BORED IN 1903.

SWEDE CORNERS AND VICINITY.

Over a small area in the vicinity of Swede Corners the wells have an unduly high temperature, out of all proportion to their depth. In four wells at Swede Corners, 100 to 159 feet deep, the temperatures range from 56° to 61°. The high temperatures extend 2 miles southward, and in the northwest corner of sec. 19, T. 43 N., R. 8 E., a well 220 feet deep has a temperature of 58½°. A quarter mile south the well temperature drops to 53°, and a quarter mile southwest of that it is 45°, which is normal in the valley for a well 100 feet deep. One-half mile northeast of the Corners the temperature is 58° and 54°, but a mile and a half northeast it drops to 45° for a well 126 feet deep. Due eastward the temperatures resume the normal at about the same rate. No reason is apparent for these excessive temperatures except the probability of more recent uncooled lavas at no great distance below. Igneous rocks project above the valley slope 2 miles west and also 3 miles north of the Corners. It seems probable that there is in this vicinity an intrusive sheet of lava of small extent a short distance below the surface, the heat radiating from which raises the temperatures in the affected area.

A 3-inch well in the NW. ¼ SW. ¼ sec. 7, T. 43 N., R. 8 E., is reported to have this section:

Section of well south of Swede Corners.

	Thickness.	Depth.
	Feet.	*Feet.*
Recent: Gravel	10	10
Alamosa formation:		
White clay	70	80
Blue clay	32	112
Sand (first flow)	1	113
Blue clay	34	147
Sand and gravel (strong flow)	9	156

The well has a flow of about 130 gallons per minute. The temperature is 61°.

In the northwest corner of the SE. ¼ sec. 6, half a mile northeast of the Corners, a well is reported with this section:

Section of well northeast of Swede Corners.

	Thickness.	Depth.
	Ft. in.	*Feet.*
Recent: Soil and gravel	12	12
Alamosa formation:		
Clay	110	122
Sand (first flow)	1	123
Clay	37	160
Sand (second flow)	1	161
Clay	19	180
Gravel (third flow)	9	189
Hard layer (fourth flow)	1	189

The well is 2 inches in diameter and the flow rises 3 inches above the casing. The temperature is 58°.

In lot 1, in the northeast corner of the same section as the last-described well, there is a 3-inch well, whose water has a pronounced chalybeate taste and leaves a yellowish rusty deposit on the sides of the stream running away from the well.

WARNER NEIGHBORHOOD.

In the neighborhood of Warner schoolhouse the supply of water from the irrigation canals has been inadequate for several seasons, and the dependence is almost altogether on artesian water. Most of the wells sunk for irrigation purposes are 3 inches in diameter, but recently several 4, 5, and 6 inch wells have been put down for that purpose. These secure good flows at an average depth of about 200 feet. The following section is given by local well drillers as typical of the region:

Section of well near Warner schoolhouse.

	Thickness.	Depth.
Recent:	*Feet.*	*Feet.*
Soil and alluvium	5	5
Wash gravel and sand	75	80
Alamosa formation:		
Clay	100	180
Sand, gravel, and clay (several small flows and one strong one)	40	220

MOFFAT AND VICINITY.

All the wells in the low ground about Moffat and extending north toward Mirage station have good flows ranging from 50 to 100 gallons or more a minute. The sketch plan of the village of Moffat (fig. 10) shows the location and number of the wells in that place.

The Denver and Rio Grande Railroad well at Moffat is one of the deepest wells in the valley. No geologic record of the well is available. It is 1,045 feet deep. The bore is 8 inches for 300 feet, and 3 inches from that depth to the bottom. The first flow was struck at 365 feet, the fourth and largest flow at 880 feet, and the sixth flow at a depth somewhat greater than 1,000 feet. The large flow was cased off, so that only the lower flow is now running. This has a head of over 30 feet and discharges about 207 gallons a minute into the water tank 27 feet above the ground. Small pecten-like shells an inch in diameter are reported at a depth of 900 feet. An analysis of water from this well will be found in the table of analyses on page 112.

Along the course of the Rito Alto from Moffat to the flowing-well limit there are a number of good wells, principally on the Shellabarger, Wales, and Frazee ranches. A 2-inch well in the northeast corner of sec. 4, 2 miles northeast of Moffat, is 300 feet deep, cased for 200 feet. It has a flow of about 70 gallons a minute. The well has a head of over 32 feet. In sec. 34, half a mile northeast of the last-mentioned well, a 3-inch well, 770 feet deep and cased to 660 feet, has a good flow. A 3-inch well a short distance northeast, with a depth of 308 feet, has a flow which rises 3 inches over the casing.

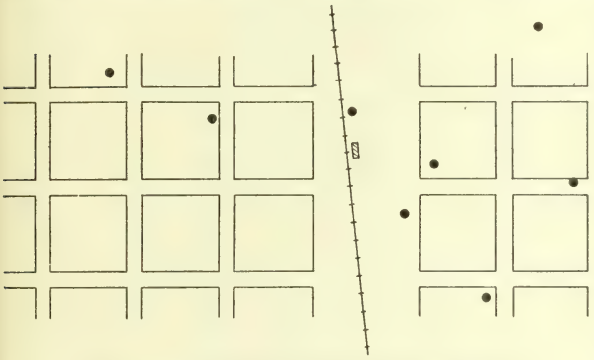


FIGURE 10.—Plat of Moffat, showing location of wells.

At A. Shellabarger's house there is a well 665 feet deep, which is cased 3 inches in diameter to a depth of 300 feet and 2 inches in diameter to a depth of 616 feet. Much difficulty was experienced in sinking this well, owing to the cobblestones that lay scattered all the way through the sand and clay. It was necessary to attach a perforated pointed steel shoe to the bottom of the casing in order to force it down. A section of the well is as follows:

Section of Shellabarger well.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay and sand with cobblestones	300	300
White clay	1	301
Sand (good flow)	2	303
Clay	37	340
Sand (flow)	2	342
Sand and clay (flows about every 20 feet)	274	616
Clay	24	640
Gravel below (strong flow).		

The water has a temperature of 61°. A 2-inch well near by, which draws from the flow at 300 feet, now yields 8 or 10 gallons per minute with a head of 4 feet. Originally the head was 11 feet and the flow about 30 gallons a minute. The temperature is 51°.

At the Frazee house, near the center of sec. 14, a well 367 feet deep has a temperature of 53°. Flows were struck at 220, 260, and 335 feet in depth, the first two being light.

MIRAGE AND VICINITY.

Mirage is situated just on the limit of the flowing-well area, and a number of wells which once flowed now lack a few feet of rising to the surface. South and west of the town the wells get good flows. A 3-inch well on the Davidson ranch, in the SE. ¼ sec. 4, a half mile south of the post-office, has a flow of 25 gallons a minute. Flows were struck at 120, 155, 185, and 213 feet in depth.

Another well on the Davidson ranch, in the NE. ¼ sec. 3, three-quarters of a mile east of the post-office, is 613 feet deep, cased to 400 feet. No water was struck that would flow. At 613 feet water rose within 6 inches of the surface. Solid rock, believed to be sandstone by the driller, was found at 613 feet.

A well near the middle of the south side of the SW. ¼ sec. 34 was originally a flowing well, but the water now stands 6 feet from the top.

The well at Tobler's, in the northeast corner of the SE. ¼ sec. 33, is 218 feet deep. When sunk six years ago it flowed, but the water is now reported to stand 16 feet from the surface. Other attempts to get water at Tobler's show sand and clay to a depth of 200 feet, where there is a layer of hardpan, thence gravel to 500 feet, below which there is 40 feet of clay.

A well near the northeast corner of sec. 33 is 435 feet deep. A flow was struck at 308 feet which yielded one-third gallon a minute for some time, but the flow failed and the water now stands 6 feet from the surface.

A well in the northeast corner of the SE. ¼ sec. 30 struck water at 200 feet in solid gravel. In the northwest corner of the NE. ¼ sec. 30 a well over 600 feet deep is 6 inches in diameter for 100 feet, thence 4 inches for 400 feet, and 3 inches to the bottom. This well flowed a little originally but now lacks a few feet of rising to the surface.

The fluctuations in the head of these wells are not to be considered as changes in the artesian pressure of the region but rather as local manifestations due to defects in the casing, caving in, or something of that sort. The absence of any regularity in the depth at which the flows are obtained is a result of the different conditions of deposition of the sand and clay beds in the narrowed area of the valley in this vicinity, the sedimentation here partaking more of the character of the irregular deposition in alluvial fans and cones. This feature is likely to be more marked farther north up this arm of the valley.

SAN ISABEL AND VICINITY.

In the vicinity of San Isabel post-office there are a number of good wells. A 3-inch well in the NW. ¼ NW. ¼ sec. 15, T. 43 N., R. 10 E., has a depth of 380 feet and a flow of 55 gallons a minute. The water has a temperature of 55½°, is clear and tasteless, and yields no gas,

though it is near the northern limit of the Mosca-Hooper area of gas-bearing waters. At the post-office a 3-inch well affords a large flow of water with a temperature of 57°.

In the NW. ¼ sec. 12, a mile northeast of the post-office, a 3-inch well 450 feet deep is cased to 200 feet. It has a head of over 30 feet, and a flow which rises 4 inches over the casing, yielding about 100 gallons a minute. It is situated in a reservoir and is used in irrigation.

In the SE. ¼ NE. ¼ sec. 2, in the same township as the well just described, a 3-inch well 375 feet deep has a temperature of 58° and affords a fair flow of water. A quarter mile south of this well a new 3-inch well 890 feet deep affords a fine flow of water.

On the H. Nash ranch, in the SE. ¼ NE. ¼ sec. 7, T. 43 N., R. 11 E., just north of the Baca grant, a 3-inch well reaches a depth of 865 feet, cased for 520 feet. Three flows were struck, the lowest of which is reported to jet the water 6 inches above the casing, indicating a yield of 125 gallons a minute. A section of this well is as follows:

Section of Nash well.

	Thickness.	Depth.
	Feet.	*Feet.*
Recent: Gravel and red sand	85	85
Alamosa formation:		
Yellow clay	15	100
Red sand	30	130
Yellow clay	70	200
Red sand	70	270
Black sand	100	370
Blue clay	150	520
Red and white sand (flow, 1-inch jet)	85	605
Blue clay	100	705
Hard white sand (flow, 3-inch jet)	30	735
Blue clay, hard	100	835
White sand (flow, 6-inch jet)	30	865

The total cost of the well was $300.

BACA GRANT.

The eastern limit of the flowing-well area passes through the Baca grant, taking in a strip on the west side of the grant in which flowing wells can be got, widening from 3 miles on the north to over 5 miles on the south. The ranch is given over to stock raising, with some native-hay land; so most of the wells have been sunk to obtain stock water. Several deep wells that failed to get water are described under the head of nonflowing wells in the vicinity of Crestone (p. 100).

The well at the sheds is 3 inches in diameter and 481 feet deep. It flows 8 to 10 gallons a minute and has a temperature of 62°. The well by the lake in the southwestern portion of the grant is 3 inches in diameter, with a flow of 25 gallons a minute. The water is very slightly tinted and there is a good flow of gas. At the South Camp the 3-inch well has a temperature of 47° and a flow of 8 gallons a minute.

MEDANO RANCH.

On the Medano ranch there are twenty-seven 2 and 3 inch wells ranging from 200 to 600 feet in depth. The flows in general are good. Those on the west side of the ranch usually have more or less gas, and the water shows a slight brownish tint, in common with the waters of the Mosca-Hooper district.

One of these, in the SE. $\frac{1}{4}$ sec. 7, T. 40 N., R. 12 E., known as the Baker well, is 476 feet deep. It is cased for some distance with 2-inch pipe, and to the bottom with $1\frac{1}{4}$-inch pipe. Small flows were struck at 121, 165, and 476 feet. The well went through coarse sand much the greater part of the distance, and there was but a small amount of clay.

CALKINS RANCH.

On Mrs. A. M. Calkins's ranch near the center of sec. 1, T. 38 N., R. 12 E., of three wells 217 to 228 feet deep, two struck flowing water and one, the easternmost, failed to get a flow. In the two wells water was struck at 160 feet and lacked 2 feet of reaching the surface. The flow was struck at 228 feet.

A well on the same ranch in the SE. $\frac{1}{4}$ sec. 2, T. 38 N., R. 12 E., gave the following record:

Section of Calkins well.

	Thickness.	Depth.
	Feet.	*Feet.*
Recent: Gravel and sand	50	50
Alamosa formation:		
Clay	10	60
Black sand (water rose just to surface)	70	130
Clay	50	180
Black sand (second flow)	60	240
Clay	50	290
Black sand (strong flow)	10	300

A 2-inch well 195 feet deep in sec. 16, T. 38 N., R. 12 E., bored in 1902, is reported to have thrown a jet 12 inches above the casing when new and not to have failed any since. A section of the well is reported as follows:

Section of well in sec. 16, T. 38 N., R. 12 E.

	Thickness.	Depth.
	Feet.	*Feet.*
Recent: Gravel (cased)	95	95
Alamosa formation:		
Blue clay	100	195
Gravel size of pigeon's egg (strong flow)	1	196

CENTRAL OR MOSCA-HOOPER REGION.

OCCURRENCE OF GAS AND COLORED WATER.

Lying in the trough of the valley and stretching from a point 4 miles northeast of Alamosa within 3 miles of Moffat, with a length of 30 miles and an average width of 8 miles, is an area in which gas is mingled with the waters of the deeper wells. Coinciding with this area, but extending 3 or 4 miles farther west, is a region in which the water of the deeper wells is colored. This color varies from the lightest tints of brown or brownish yellow to a decided brownish color, like that of swamp water or water that has collected in rotten wood. Both areas are shown on the map accompanying this report (Pl. I). This region of tinted and gas-bearing water is generally known as the Mosca-Hooper district.

In explanation of this occurrence of gas and tinted water there is to be noted the significant position of the area in the trough of the valley, with which it so strikingly corresponds in outline. Just as this is now the lowest portion of the valley, it probably was so in the later stages of deposition of the Alamosa formation. The occurrence, particularly in this district, of wood, bark, peaty moss, and seeds has already been noted. The high content of alkalies in the tinted waters is shown in the table of analyses on page 112. That this is not a separate basin, and that the same aquifers which farther west yield the usual pure water of the valley here yield the tinted alkali and gas-bearing water, is proved by the continuity of the aquifers, the evidence of which has already been shown (p. 44). Consideration of these facts leads to the conclusion that there were arid periods during the deposition of the water-bearing sands and clays of the Alamosa formation, when the water of the lake shrank to a small shallow area in the trough of the valley, and that this area of more or less alkaline water afforded a growth of vegetation, in particular of mosslike plants. Later, when the deposition of the series was complete, these interbedded alkaline and peaty sands and clays became water bearing. As water was drawn from the area pure water from the outside took its place and in turn dissolved the alkalies and took up the peaty infusion. Thus in time, with the continual draft upon the waters of the area, they must tend to become fresher and less highly colored and eventually, in the remote future, to become like the other water of the valley. The extension of the colored-water area beyond the gas-bearing area, west of Mosca and Hooper, admits of an interesting speculation. It seems reasonable that the heavy drain upon the water-bearing series in the region of closely crowded wells west of Mosca and Hooper has caused a movement of the waters out from the Mosca-Hooper district toward the region of heavy drain, and that this movement carried the colored water beyond its

original bounds. Just why there was not a similar migration of the gas is not so clear, though it is true that the gas occupying the local irregularities in the upper surface of the aquifers would not be so subject to lateral movement as the water. Furthermore, it is probable that some of the gas is stored in lenses of sand inclosed in the clay beds and not laterally connected with the aquifers. In such a situation it would not be subject to movement like that of the water.

The presence of gas has led to some prospecting for oil. The log of the deepest well sunk by the Chicago and San Luis Oil Company, 4½ miles due east of Mosca, is given on page 43. Oil scum on the water and oil on the drill rope are reported from this well, but no flow of oil was struck, and prospecting is at a standstill. In general it is not to be expected that oil and gas will be struck in an artesian basin; yet the Florence (Colorado) oil field is an instance of such a relation. The oil there arises from carbonaceous shales and is stored in lenticular bodies of sandstone inclosed on all sides by shale. From the sections and discussions in the preceding pages it is clear that the Alamosa formation is made up of a series of persistent clay and sand beds, so that the occurrence of lenticular beds of sand near the center of the valley is not to be expected. It may be, however, that in the local heavy beds of clay reported in the region there are sand lenses; and the possibility of gas occurring in these has already been mentioned. It may safely be predicted, however, that no considerable quantity of oil will ever be found in the Alamosa formation, for the beds of that formation are but slightly carbonaceous and the quantity of gas already discovered is as great a volume of hydrocarbons as the carbonaceous content of the formation could reasonably be expected to furnish. Further, the underlying Santa Fe formation (gravel beds interbedded with lava flows) offers very little prospect for oil below the Alamosa formation. The chance in the San Luis Valley of striking any oil-bearing beds of greater age than these at any depth, however great, is exceedingly remote.

MOSCA AND VICINITY.

No accurate log exists of any deep well in the immediate vicinity of Mosca, but the geologic section of the "oil well," 1,283 feet deep, 4½ miles east of Mosca, has been given on page 43. In the village itself there are 17 wells, the location of which is shown on the town plat (fig. 11).

The town well in Mosca is 400 feet deep. The first flow, at 160 feet, just comes to the surface. This flow is clear. Other flows, every 15 to 30 feet down to a depth of 400 feet, are colored with various tints of light brown. The chemical composition of the water is given in the table of analyses, page 112.

A 5-inch well near the schoolhouse in Mosca is 500 feet deep. The temperature is 66° and the flow is about 50 gallons a minute. The water is of a decided brownish color and has a slight taste, neither acid nor salty, yet repellent.

The Mosca Milling and Elevator Company's well is 4 inches in diameter and 600 feet deep. The first flow was struck at 200 feet and other flows about every 50 feet down to the bottom of the well. The well furnishes a large flow of water, which has a very slight brownish tint and a very small amount of gas. The tempera-

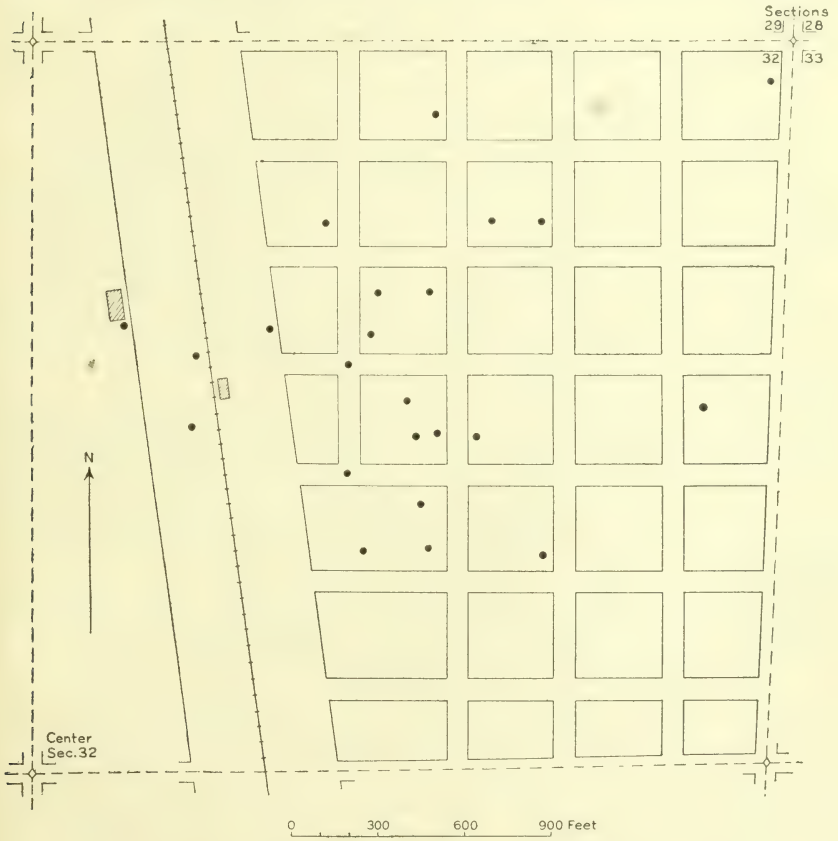


FIGURE 11.—Plat of Mosca, showing location of wells.

ture is 69°. An analysis of the water will be found in the table of analyses, page 112.

A well in the SE. ¼ sec. 16, a mile south of Mosca, is 385 feet deep. The water has a temperature of 60°, a light-brownish tint, and a slight taste of sulphur. This is the second flow, but the first flow, at 80 feet, is reported to be good clear water.

At Peter Andersen's, in the NW. ¼ SW. ¼ sec. 26, T. 39 N., R. 10 E., the well is cased 2 inches in diameter to a depth of 340 feet and 1¼

inches in diameter to a depth of 500 feet, the first flow, at 200 feet, thus being cased off. The upper flow, from a depth of 340 feet, has a temperature of 62° and the lower flow, from a depth of 500 feet, a temperature of 63°. There is probably a greater difference than this in the real temperatures of the flows, but flowing alongside each other to the surface they tend to come to an average. The upper flow has a perceptible color and a peculiar taste, such as one would expect of water standing in a hollow stump. The lower flow has a pronounced taste and color, and there is perceptible a very small amount of gas. The upper flow yields about 1 gallon and the lower about 4 gallons a minute. An analysis of the water from the lower flow is given in the table of analyses on page 112.

A 3-inch well in the NE. ¼ sec. 27, one-fourth mile northwest of Andersen's well, of unknown depth, has a temperature of 66°. The water from this well is very dark and kills all the vegetation along the overflow from the well in a strip 10 to 15 feet wide. Over this area white crusts of alkali have formed around the drying edges of the stream.

A mile south of Andersen's well, in the northwest corner of the SW. ¼ sec. 35, a 2-inch well, 500 feet deep, which has now ceased to flow, furnished water for the analysis by Dr. W. P. Headden, which is given in the table of analyses on page 112.

In the NW. ¼ NW. ¼ sec. 8, T. 38 N., R. 11 E., there is a 3-inch well 800 feet deep which flows 3 inches over the casing, indicating a flow of about 90 gallons a minute. The temperature is 71°. There is a slight flow of gas. The water has a light-yellowish tint and a slight taste of sulphur. Its chemical composition is indicated in the table of analyses, page 112.

Several miles west of Mosca, on the J. M. Chritton ranch, the following section occurs, according to Professor Carpenter:

Section of Chritton well.

	Thickness.	Depth.
Recent:	*Feet.*	*Feet.*
Dark sandy loam	7	7
Coarse sand and gravel	13	20
Alamosa formation:		
Fine light-yellow sand	22	42
Yellow impervious clay	18	60
Blue clay	98	158
Black sand (small flow)	1	159
Blue clay	4	163
Fine black sand (fine flow)	3	166
Blue clay	45	211
Fine black sand (flow)	12	223
Blue clay	53	276
Black sand (strong flow).		

On the Watson ranch, 5 miles northwest of Mosca, there are two 3-inch wells which are both 712 feet deep and are cased to a depth of 200 feet. One of them is in the SW. ¼ sec. 35, and the other is in the SE. ¼ sec. 34, T. 40 N., R. 9 E. The flow of these wells has a temperature of 63° and forms a jet 5½ inches high, indicating a flow of approximately 120 gallons a minute. A section of this well is reported as follows:

Section of Watson well.

	Thickness.	Depth.
	Feet.	*Feet.*
Recent: Gravel and sand	60	60
Alamosa formation:		
Yellow clay	4	64
Gray sand	16	80
Blue clay	30	110
Black sand (water, no flow)	3	113
Blue clay	87	200
Sand (first flow, small)	2	202
Blue clay	38	240
Sand (second flow)	2	242
Blue clay	58	300
Sand (third flow)	2	302
Clay with sand beds (numerous flows)	333	635
Sand (main flow)	12	647
Clay with sand beds (small flows)	65	712

HOOPER AND VICINITY.

There are 23 wells shown on the Hooper town plat (fig. 12). Most of these flow through the drill rods, consisting of 1-inch pipes, which are allowed to remain in the wells in order to lessen the liability to cave in that is shown by wells in this vicinity.

The Garrison Mill and Elevator Company's well was sunk in August, 1897, has a diameter of 4½ inches, is cased to the bottom, and flows 70 gallons a minute. The temperature is 69°. The water has a pronounced taste of soda and a slight brownish tint, with a very small flow of gas. An analysis of the water will be found in the table of analyses on page 112. The log is as follows:

Log of Garrison Mill and Elevator Company well.

	Thickness.	Depth.
	Feet.	*Feet.*
Recent: Surface gravel and sand	90	90
Alamosa formation:		
Blue clay	15	105
Black sand (no flow)	5	110
Blue clay	90	200
Fine sand (first flow, small)	5	205
Blue clay with 2-foot beds of sand and flows every 50 feet (various flows)	445	650
Blue clay, in strata 15–30 feet thick, with interstratified sand beds 12 feet thick (various flows)	90	740

The Denver and Rio Grande Railroad well, situated 250 feet southeast of that described above, has the following record:

Log of Denver and Rio Grande Railroad well at Hooper.

	Thickness.	Depth.
Recent:	*Feet.*	*Feet.*
Soil	3	3
Gravel	10	13
Alamosa formation:		
Sand	52	65
Blue clay	143	208
Blue clay with sand strata	124	332
Sand (small flow)	1	333
Clay and sand (various flows)	251	584
Blue clay	30	614
Sand below (heavy flow).		

The diameter of the well is 4 inches. The flow originally had a head 27 feet above the top of the ground and the well had a flow of

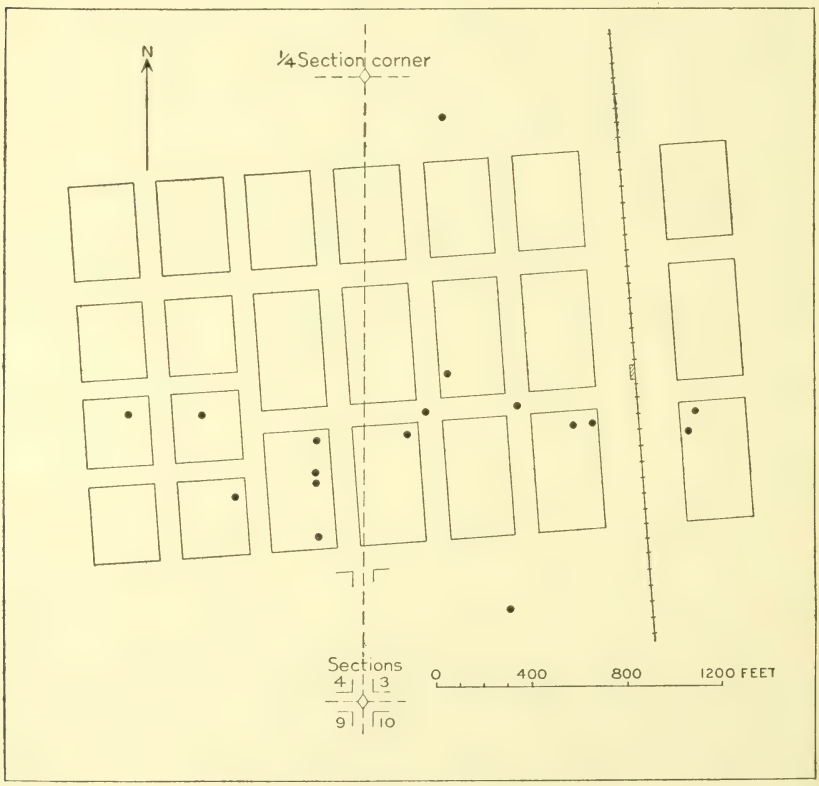


FIGURE 12.—Plat of Hooper, showing location of wells.

50 gallons a minute. The water has a decided brownish tint and is without gas. An analysis of the water is given in the table of analyses on page 112.

The town well, situated in the intersection of Fourth avenue and Main street, is about 300 feet deep. It is cased for a short distance with 3-inch casing, and inside this is a 2-inch casing reaching to the bottom of the well. The flow is approximately 1 gallon a minute but was originally about 4 gallons. The temperature is 53°. The water is clear, with a slight taste of sulphur. The sodium carbonate in this well, as determined by the electrolytic method, is 103 parts per million.

A well in block 8, in the northeast corner of the town, is 1 inch in diameter and 425 feet deep. It has a head somewhat more than 14 feet. The temperature is 54° and the water clear.

A 2-inch well in the northwest corner of sec. 6, T. 42 N., R. 10 E., has a temperature of 65° and flows 2½ inches above the casing, indicating a volume of 35 gallons a minute. The water has a decided brownish tint. An analysis of this water, published by the United States Department of Agriculture,[a] is given in the table of analyses on page 112.

A well one-half mile west of Swede schoolhouse, in the SE. ¼ sec. 19, T. 41 N., R. 10 E., struck flows at the following depths:

	Feet.
First flow	220
Second flow (good)	380
Third flow	450
Fourth flow	510
Fifth flow	550

The well is cased for 112 feet. The flows below 380 feet are now shut off by caved walls. The temperature is 59° and the well has a flow of 15 gallons a minute. The water has a slight brownish tint.

In the corral on the ranch of George W. Clark, in the SE. ¼ NW. ¼ sec. 18, T. 41 N., R. 11 E., there is a 3-inch well 630 feet deep, cased to 360 feet. It has a temperature of 60° and a discharge of about 70 gallons a minute. The water has a faint brownish tint and is highly charged with gas. The well is equipped with a device for separating the gas from the water and storing it, a reproduction in miniature of a municipal gas-storage tank, which is shown in Plate XII, *A*. Collected in this way the well affords a sufficient volume of gas for a cook stove and one gas jet. The gas, in common with

[a] Field operations, Bureau of Soils, 1903, p. 1114.

that of the Mosca-Hooper district, has a strong benzine-like odor. The section of the well is as follows:

Section of Clark gas well.

Material.	Thickness.	Depth.
	Feet.	*Feet.*
Recent (in part): Sand and gravel	185	185
Alamosa formation:		
Clay	15	200
Sand (first flow, small)	50	250
Clay	25	275
Sand (second flow)	10	285
Clay	30	315
Sand (flow with gas)	10	325
Clay and sand (flows with gas every 20 to 30 feet)	252	577
Clay	50	627
Very hard stratum	(a)	627
Sand (strong flow of water with gas)	3	630

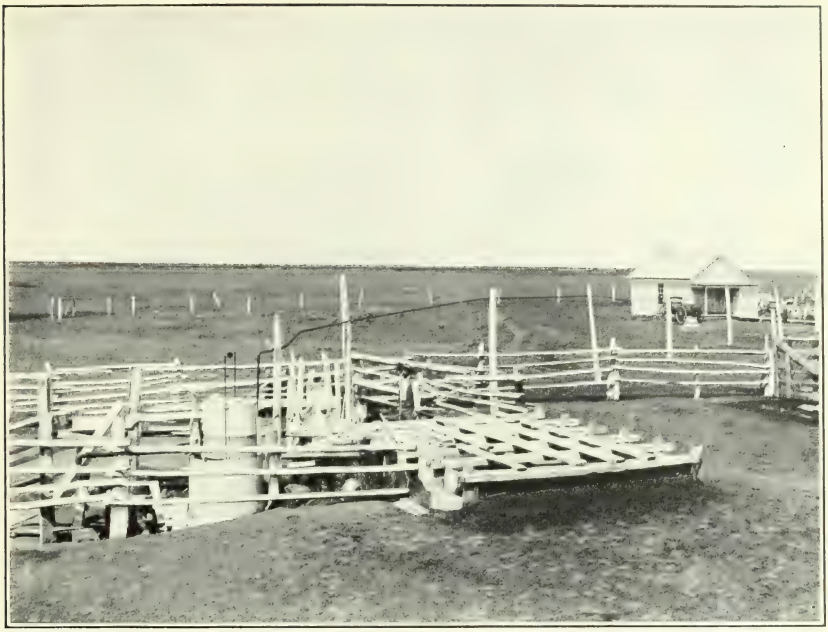
a 1 inch.

On the Star ranch, in sec. 26, T. 42 N., R. 10 E., there are two 3-inch wells, both of which yield gas. The one at the corral, supposed to be between 400 and 500 feet deep, has a temperature of 48° and flows less than a gallon a minute. The water is of a light-yellow color. The escaping gas forms a frothy foam, which stands 6 inches above the surface of the water and burns with a bright yellow flame. Half a mile southeast of the corral is the other well, bored 3 inches in diameter to a depth of 400 feet and 2 inches in diameter to a depth of 800 feet. The water has a temperature of 70°, a light-brownish tint, and a peculiar saltish taste. The flow of water, mixed with gas, fills the 2-inch horizontal discharge pipe and amounts to 20 or 25 gallons a minute. It is used for stock water. The well affords a considerable volume of gas, which burns with a yellow flame 2 feet high. The amount of gas would apparently be ample to run a heating or cooking stove or several gas jets.

KINNEY RANCH.

On the Stephen Kinney ranch there are ten wells, ranging from 500 to 1,018 feet deep, all of which have, for the valley, copious flows of gas though not very good flows of water. Owing to the tendency of 2 and 3 inch wells to become choked up by indrawn chunks of clay, the drill rods were left in all these wells, so that the water now flows through 1-inch pipes. An unusual feature of the geologic structure of this region is the reported preponderance of clay, the scarcity and small size of the sand beds, and the great depths to the flows.

The house well, near the center of sec. 35, T. 43 N., R. 10 E., is cased 2 inches in diameter for 454 feet, shutting off the first flow, a small one with much gas, at 450 feet. The 1-inch casing reaches to



A. CLARK'S GAS WELL AND STORAGE TANK.

B. HUNT SPRINGS, LOOKING EASTWARD ACROSS THE NORTH END OF SAN LUIS VALLEY.

630 feet and the depth of the well is 639 feet. The flow is about 10 gallons a minute, with much gas. The water has a temperature of 63° and a taste and tint similar to the other gas-bearing waters of the Mosca-Hooper district. A short distance from this well another one has been recently sunk with the object of obtaining gas for domestic uses. The diameter is 2 inches and the depth 766 feet. The temperature of the water is 68°. A good flow of gas was obtained, which is collected and stored in a suitable tank.

In the SW. ¼ sec. 3, T. 42 N., R. 10 E., there is a well cased 3 inches to 864 feet and 2 inches to 995 feet. The total depth of the well is 1,018 feet. The well stopped in a black sticky mud, which could not be handled by the hydraulic process of boring. A small flow was found at 600 feet and a better one at 700 feet, but both had so much gas that they choked up the pipes. According to the driller, Mr. Charles Speiser, the gas here caused a geyser-like intermittent flow, which, at intervals of an hour, caused the water to flow to the top of the derrick, 32 feet high. Later the interval lengthened to four or six hours, and mud and water were thrown to a height of 60 and 75 feet. The rise and fall of the column was gradual. White at first with the foam of included gas, the column would afterward become black with indrawn mud and sand. When the foam was ignited at the bottom the flame would run to the top of the column and fire balls would drop down the side and reignite the foam at the bottom, the flame mounting the column again. After a month the well became choked. It was cleaned out and the gas was cased off. Another flow was found at 760 feet, which again threw mud and water over the derrick. After the escape of the gas a soft sandy mud filled with "seeds" was pumped out. The "seeds" floated upon the water and covered it. They were soft and were brownish in color, turning to black in sunlight. This flow was likewise cased off, and but a single weak flow, at 830 feet, was found to the bottom of the well. This well is but 8 miles southeast of the Denver and Rio Grande Railroad well at Moffat, which is nearly of the same depth and which struck such large flows of water.

Another well in the southwest corner of sec. 11, T. 42 N., R. 10 E., is 835 feet deep. No flow at all was noticed in drilling this well, but a small one with considerable gas came in afterward. The flow of water is irregular, sometimes very small, sometimes spouting (mixed with gas) 4 feet over the casing, and again flowing gas only.

JACOBS RANCH.

The Jacobs ranch marks the extreme northwestern extent of the gas region. Several wells yield considerable gas, but no use is made of it.

In the NW. ¼ sec. 26, T. 43 N., R. 9 E., a 2-inch well 500 feet deep is cased for 125 feet. It has a flow of 25 gallons a minute. The

water has a temperature of 58° and the usual taste of the gas-bearing water, but no color is visible. There is a fair flow of gas.

At the ranch house, in the NE. ¼ sec. 34, the 3-inch well is 404 feet deep and is cased for 224 feet. It flows about 40 gallons a minute. The water has a temperature of 57°, a slight taste, and a faint color. It has also a good flow of gas.

The strongest flow of gas on the ranch, however, is found in the NE. ¼ sec. 10, T. 42 N., R. 9 E., in a 3-inch well 650 feet deep, cased for 325 feet. The flow of water is reported to be about 70 gallons per minute.

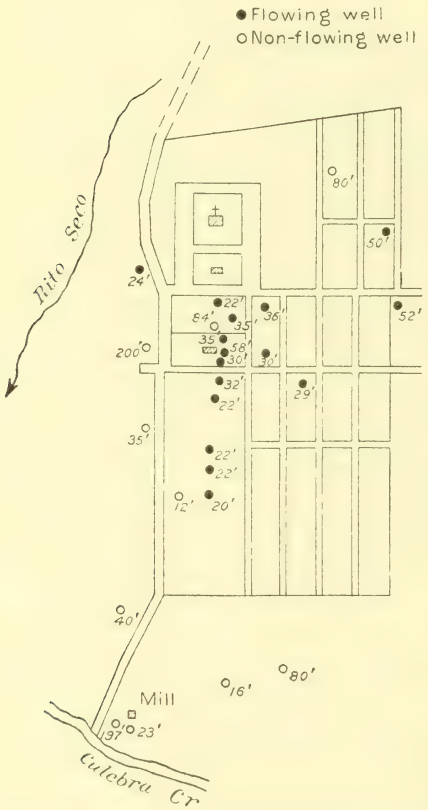


FIGURE 13.—Plat of San Luis, showing location of wells.

SAN LUIS VILLAGE.

San Luis village lies altogether outside of the artesian area of the valley. Culebra Creek cuts through the lava-capped San Pedro Mesa and east of the mesa, together with the Rito Seco, it has cut out of the Santa Fe formation a parklike valley 3 miles wide and several miles long. Situated on the Rito Seco, just above the point where it joins Culebra Creek at the gap in the mesa, is the village of San Luis, a plat of the older portion of which is shown in figure 13. Within the town limits in the last few years a number of wells have been bored which yield flowing water. In a few other wells the water comes almost to the surface. In two wells of this sort, where the water rises within 6 or 8 inches of the surface, a hole 3 or 4 feet deep has been dug about the mouth of the well and the casing cut off low enough to give a flow of a gallon or so per minute. The waste water escapes into the gravel and causes no inconvenience. The distribution of the wells and their depth are shown in figure 13. The flowing wells are bunched about the court-house square but extend a little farther to the south; outside of this area the wells either do not strike water or yield water that does not rise to the surface. In this area of flowing wells there seem to be two flows, one at a depth of about 20

feet and another at 50 to 60 feet. Most of the wells draw from the upper flow. Of those deep enough to reach the lower flow one at least draws from the upper flow. Judging from the small size of the artesian area, its shallowness, and the irregularity of the formations, as seen in the well sections, the flow is probably due to underflow of the Rito Seco, and its localization to irregularity of deposits in some prehistoric channel of that stream. The temperature (in December) ranges from 45° to 47° but bears no relation to the depth of the well, depending rather on the rate of flow of the well; the weaker wells have the lower temperature because the water in its slow rise through the ground has opportunity to cool to surface-soil temperatures.

The court-house well, bored in 1892, is 3 inches in diameter and 58 feet deep, cased all the way. The flow was struck at 25 feet, under a few inches of clay, and the well was continued in gravel to the bottom without increasing the flow. The temperature is 46°.

Doctor Smith made two unsuccessful attempts to find water just west of the court-house, across Main street. The deepest hole gives the following section:

Section of Smith well.

	Thickness.	Depth.
	Feet.	*Feet.*
Alluvial clay	15	15
Sand	5	20
Hard clay	1	21
Red sand with streaks of blue sand (no flow)	179	200

The water sank as fast as it was pumped into the well in drilling. Another well near by, 70 feet deep, also failed to get water. A third well was sunk in the court-house yard and struck a small flow at 20 feet and a better one, yielding 5 gallons a minute, at 59 feet. This is the same flow that the court-house well strikes.

W. S. Parrish bored a third well in the court-house yard, south of the other two. This is only 30 feet deep, but it evidently reaches the same flow as the others; for when it is allowed to flow freely, its orifice being lower than those of the other two, their flow is completely stopped. This difficulty is remedied by reducing the discharge pipe of the Parrish well to one-half inch; then the others are affected but little. The water is piped to Mr. Parrish's house, near the southwest corner of the town.

Five wells in a row along Main street south of the court-house yard are 22 to 32 feet deep and have flows varying from 1 to 5 gallons a minute. The temperature of the shallow ones is 47°. In the blocks immediately east and southeast of the court-house three wells are 30 to 36 feet deep, the flow ranging from 1 to 2 gallons a minute and the temperature from 45° to 47°.

East and west of the schoolhouse and church the wells do not flow, the water lacking from 6 inches to 5 feet of reaching the surface.

South of the village, in the neighborhood of the mill, Mr. Parrish made several attempts to strike flowing water but failed in each attempt, though the elevation is about 20 feet less than that of the court-house yard. The deepest well, 197 feet deep, furnishes this section:

Log of Parrish's mill well.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil	4	4
Gravel	23	27
Quicksand and streaks of clay	75	102
Hard sand	95	197

The water rose within 3 feet of the surface. Another well was sunk to a depth of 80 feet at a point 300 yards northeast of the mill, in the vicinity of several springs. This showed a section similar to that just given. Above a depth of 40 feet the water rose within 2 feet of the surface, but as boring progressed below that depth the water sank instead of rising.

A well in the bottom, 1 mile southeast of the village, went 60 feet in bowlders, and one in the gap one-half mile west of the village went 25 feet in bowlders with no water.

NONFLOWING WELLS.

ANTONITO.

Plate III, *A*, shows a view looking west from the vicinity of Antonito at the eastward-sloping lava-capped mesa about Los Mogotes Peak. The lava sheet can be seen to approach the level of the valley bottom and merge with it. This lava sheet is reached in various wells near Antonito. The town well reaches a depth of 400 feet. The first 235 feet is a cribbed shaft measuring 3 by 5 feet. In the bottom of this shaft a hole was bored 165 feet farther. A geologic section of the well, as reported by Mr. E. L. Myers, is as follows:

Section of Antonito city well.

Material.	Thickness.	Depth.
	Feet.	*Feet.*
Recent: Loose gravel and soil	35	35
Santa Fe formation:		
Solid lava	22	57
Lava ash	10	67
Gravel	25	92
Coarse bowlders	35	127
Gravel and sand becoming finer	96	223
Conglomerate cement	3	226
Gravel and sand	9	235
Gravel and sand (bored)	165	400

From this well there is pumped weekly 70,000 gallons of water, being the whole supply of the town for domestic purposes. A gasoline engine lifts the water 250 feet into a 35,000-gallon tank. The water is cold, tasteless, and hard.

The Denver and Rio Grande Railroad well is about 350 feet from the town well. The log of this well is as follows:

Log of Denver and Rio Grande Railroad well at Antonito.

	Thickness.	Depth.
	Feet.	*Feet.*
Recent: Gravel and bowlders	38½	38½
Santa Fe formation:		
Solid lava	35	73½
Lime cement	1½	75
Clay and bowlders	55	130
Marl	18	148
Cemented gravel	13	161
Marl	17	178
Cemented gravel	20	198
Marl	8	206
Cemented gravel (water)	20	226
Loose gravel	1	227
Cemented gravel	13	240
Loose gravel	2	242

The water rises in this well 16 feet. With two hours' hard pumping the water is lowered to 2 feet, after which 4,000 gallons per hour can be taken out without affecting the water level. The analysis of this water is given in the table of analyses, page 112. The high percentage of this water in $CaCO_2$ (whence its hardness) is noticeable, being exceeded in this respect only by the water from the Valley View Hot Springs, so far as the waters of the valley have been analyzed.

MANASSA AND VICINITY.

Manassa lies just south of the southernmost limit of flowing wells. Sharp little lava hills rise out of the valley half a mile south and 2 miles east of the town. Several attempts to obtain flowing water have been made within the limits of the town and in the vicinity. A well 125 feet deep in the northeast portion of the town went through bowlders. The water is reported to rise within 3 feet of the surface. A well in the schoolhouse yard, said to be 74 feet deep, struck water, which rises within 12 feet of the top.

During the winter of 1903–4 the State bored an experimental well in the schoolhouse yard. The log of this well, as furnished by the state engineer of Colorado, is as follows:

Record of state well at Manassa.

	Thickness.	Depth.
	Feet.	*Feet.*
Recent: Sand and bowlders	77	77
Alamosa formation:		
Clay	7	84
Clay and sand	5	89
Blue clay	3	92
Sand	62	154
Fine sand	14	168
Coarse sand	21	189
Coarse sand and fine gravel	11	200
Fine light sand	10	210
Coarse sand	70	280
Santa Fe formation (?):		
Lava bowlders	5	285
Dark sand and clay	11	296
Fine clay sand	9	305
Coarse sand	29	334
Coarse sand and bowlders	5	339
Fine clay sand	3	342
Red lava sand	18	360
Lava cobblestones	20	380
Clay and sand	55	435
Fine black sand; some clay	15	450
Volcanic ash (sand)	62	512

It is evident from the preponderance of sand and gravel in this well that Manassa lies at the extreme edge of the alternating series of clays and sands which hold the artesian water under pressure, and that southwest of the town the clays will be found to be replaced altogether by sands and gravels. In that region water can not be found under sufficient pressure to reach the surface but will rise in the wells simply to the height of the general water level of the region or the underground water table.

Water was found through the entire depth of the well below the first 6 feet, except in strata of clay. The water rises within 26 feet of the surface of the ground. The well is 10 inches in diameter for the first 342 feet, and below that 8 inches in diameter.

A well on the Braiden ranch, in the SW. $\frac{1}{4}$ sec. 20, T. 34 N., R. 10 E., is 133 feet deep with a rock bottom. The water rises within 3 feet of the surface.

The McDaniell place, in the northwest corner of sec. 33, T. 34 N., R. 10 E., has a well 33 feet deep, in which the water rises within 7 feet of the surface. The section of the well is as follows:

Record of McDaniell well.

	Thickness.	Depth.
Recent:	*Feet.*	*Feet.*
Soil, gravel, and clay	31	31
Gravel	2	33
Lava below.		

Two miles northwest of Manassa, in the NW. ¼ sec. 10, T. 34 N., R. 9 E., a prospect well was sunk by the Conejos County Oil Company to a depth of 318 feet. This well is about 1½ miles from the edge of the flowing-well area and about 30 feet higher. The record of the well, kindly furnished by Mr. W. O. Meier, is as follows:

Record of Conejos County Oil Company's well.

	Thickness.	Depth.
	Feet.	*Feet.*
Recent: Gravel and sand	70	70
Alamosa formation:		
Blue clay	12	82
Black sand (first flow, rose to −1 foot)	8	90
Gravel, sand, and clay	155	245
Santa Fe formation:		
Lava	30	275
Very red granular rock	20	295
White sand (probably pumice)	5	300
Black sand (water rose to −20 feet)	4	304

CAPULIN AND VICINITY.

The wells in the vicinity of Capulin are dug wells. The usual depth is 30 feet, at which point they strike lava. A basin is made in the lava, into which the water percolates from the gravel.

North of Capulin the Knapp well is reported to show this section:

Section of Knapp well.

	Thickness.	Depth.
Recent:	*Feet.*	*Feet.*
Gravel and bowlders	200	200
Hard stratum, not rock	2	202
Sand (drill rods dropped)	32	234
Bowlders	16	250

The water rose in the well about 100 feet, that is, within 150 feet of the surface. This well is far up on the alluvial slope, as indicated by the great excess of gravel and bowlders.

East of Capulin and between that place and the Harvey ranch there are several deep wells. A mile and a half east of the village, 500 yards south of the center of sec. 10, T. 35 N., R. 8 E., several wells on the Palmer ranch reach lava at 64 and 66 feet, and afford a more permanent supply of water than the surface wells, 25 feet deep, which go dry in winter.

On the George S. Lovett place, in the SW. ¼ NE. ¼ sec. 11, a mile east of the well last described, a well gave this section:

Section of Lovett well.

	Thickness.	Depth.
	Feet.	*Feet.*
Recent: Bowlders	55	55
Alamosa formation:		
Sand	60	115
Blue clay	60	175

Water was struck at 65 feet and rose within 5 feet of the surface.

At L. D. Eskridge's place, in the northwest corner of sec. 18, T. 35 N., R. 9 E., a well shows this section:

Section of Eskridge well.

	Thickness.	Depth.
	Feet.	*Feet*
Recent and Alamosa formation: Sand and clay	150	150
Santa Fe formation: Lava	101½	251½

The water rises within 26 feet of the surface.

At S. E. Newcombe's, half a mile due east of the Eskridge well, two wells struck lava at 180 feet, and one of them penetrated it a depth of 20 feet. In the house well the water stands 10 feet from the surface, and in the barn well it rises within 3 feet of the surface.

At the schoolhouse, a quarter of a mile northeast of Newcombe's, the rock was struck at 185 feet and the water rises within 8 feet of the surface.

Joe Fred's well, in the SE. ¼ sec. 31, T. 36 N., R. 9 E., gives this section:

Section of Fred well.

	Thickness.	Depth.
	Feet.	*Feet.*
Recent: Gravel	45	45
Alamosa formation: Clay	315	360
Rock below.		

The water rose within 8 feet of the surface.

On the Harvey ranch a well in the SW. ¼ sec. 5, T. 35 N., R. 9 E., is 265 feet deep, with a flow between 10 and 12 gallons a minute. There was a small flow just over the rock, but the present supply comes from crevices in the rock, into which the well is cased for some distance. There is some uncertainty as to the depth at which

rock was reached, but apparently it was about 232 feet, at which point, according to the state engineer's report, the first flow was obtained.[a] From the same source it is learned that the original flow was reported to be 100 gallons a minute. On the same ranch there are two other wells which reach rock, one at the house and another at the barn. The former is 6 inches in diameter to rock, which was reached at about 195 feet. There was a small flow here, but the bore, reduced to 4 inches, was continued to a depth of 229 feet. This well has a flow of several gallons a minute. The well at the barn, northeast of the house, is 265 feet deep, reaching the rock at about 220 feet. This well also has a flow of several gallons a minute, and originally the water rose from it 8 feet above the surface.

These wells on the Harvey ranch, though flowing wells, are described here because they form a continuous series with the other wells just described, which struck rock but did not get flowing water. It is apparent from the difference in depth at which rock is reached in the Joe Fred well and in the others that irregularities exist in the surface of the bed-rock lava. Possibly the northeastward limit of the upper lava flow lies between the Harvey wells and the Fred well. So far as is known to the writer, bed rock has not been struck in any well north and east of that point, except at the Lambert well, 1 mile northwest of La Jara, described on page 65.

The Eskridge and Newcombe wells are artesian, though nonflowing, but the Knapp, Palmer, and Lovett wells merely penetrate the underground water table, which is probably higher near La Jara and Alamosa creeks than it is at a distance from them.

BOWEN SCHOOL AND VICINITY.

Two miles southwest of Bowen school, in the northwest corner of the SW. ¼ sec. 33, T. 37 N., R. 8 E., a well 240 feet deep gives this section:

Section of well in sec. 33, T. 37 N., R. 8 E.

	Thickness.	Depth.
	Feet.	*Feet.*
Recent: Gravel and bowlders	60	60
Alamosa formation:		
Hard clay	80	140
Sand (water)	1	141
Clay	99	240
Gravel below.		

This well is nearly 2 miles outside of the limits of flowing wells, and the water lacks 40 feet of rising to the top of the well.

[a] Rept. State Engineer of Colorado for 1889–90, p. 339.

Two miles east of north of Bowen, in the northeast corner of the NW. ¼ sec. 11, T. 36 N., R. 8 E., a well passed through 60 feet of gravel and 160 feet of clay, striking water in gravel. The water rises within 14 feet of the surface.

Four miles west of Bowen, on the Gunbarrel road, in the northwest corner of sec. 31, T. 37 N., R. 8 E., the Strauss dug well is 70 feet deep in sand and gravel. It is well up toward the apex of the Cat Creek alluvial cone, and in the wet season (about June) it fills to the top. In the fall and winter it goes nearly dry, demonstrating an annual variation of about 70 feet in the ground-water level in this part of the alluvial slope. The well is about 150 feet higher than the rim of the flowing-well area.

MONTE VISTA AND VICINITY.

From Monte Vista to Alamosa Creek the Monte Vista canal is approximately parallel with the margin of the flowing-well area, and about a mile from it. As the Monte Vista canal is practically the upper limit of settlement in the valley, except along inflowing streams, there are few wells outside of the canal, but between the canal and the flowing-well margin there are many nonflowing wells that penetrate the artesian water-bearing beds.

Two miles west of Monte Vista, in the NE. ¼ NE. ¼ sec. 34, T. 39 N., R. 7 E., on the second terrace of the Rio Grande, the water lacks 18 feet of rising to the surface. One mile south, in the NE. ¼ sec. 3, T. 38 N., R. 7 E., a well 125 feet deep failed to get any water whatever. In the southeast quarter of the same section two bore holes, 66 and 76 feet deep, struck water which failed to rise. They are reported to strike rock, but more probably they struck bowlders.

DEL NORTE.

The municipal water supply of Del Norte is pumped from the Rio Grande into a small reservoir in the side of a small hill just south of the town, from which it is distributed. Wells in town strike the underflow of the Rio Grande at short distances, furnishing a plentiful supply of wholesome water.

In 1890 an artesian well was bored at the intersection of two of the main streets of the town, reaching a depth of 450 feet. A very small flow of water was obtained, at first a stream not larger than a lead pencil, which afterward strengthened to a flow of 2 gallons a minute. The water is reported to rise from beneath a sheet of lava, though details of the geologic record of the well are not available. The water has a temperature of 54° and a decided taste of soda. No analysis is available.

LA GARITA AND VICINITY.

Wells east and south of La Garita strike water in the gravel of the alluvial slope. A well at the Dunn ranch, near the center of sec. 16, T. 41 N., R. 7 E., at 180 feet in depth, struck quicksand and water, which rose within 10 feet of the surface. This well is about 2 miles from the limit of flowing wells. To the south is the great triangular alluvial fan of the Rio Grande. The lower portion of the fan, adjacent to the flowing-well area of the valley, affords wells in which the water rises under artesian pressure to a greater or less height, according to the distance from the flowing-well limit. But in the upper part, toward the apex of the fan, the clay strata of the valley thin out and give place to sand and gravel beds. Wells in this area will be bored in gravel and sand and will yield water whose level, depending on the general water level in that region, will be higher near the Rio Grande and lower at a distance from the river.

SAGUACHE AND VICINITY.

The limiting line of the flowing-well area crosses Saguache Creek 3 miles below Saguache, which lies in the creek valley somewhat within the margin of the foothills and is surrounded by isolated lava hills. The chances of striking any water but the underflow of the creek depend upon striking gravel beds beneath the lava containing water under pressure. Several attempts to strike deep water have been made, one by the State, one by the town, and others by private citizens, but none have struck flowing water. The information recorded below has been kindly communicated by the Hon. J. H. Williams, county judge of Saguache County.

The state well, 1 mile northwest of town, reported to be 1,100 feet deep, struck water at about 75 feet, which rose within 12 or 14 feet of the surface. No record is available as to geologic formations penetrated. The well did not succeed in getting a better flow of water with greater depth.

The park well, in the public park within the town limits, is reported to be 665 feet deep. Water was struck at 65 feet in gravel and rose within 12 feet of the surface.

The Jordan well, just south of the town, is 180 feet deep, with the water level 8 feet from the surface; the Curtis well, in the eastern part of town, is 100 feet deep and has water at the same level. Several other wells in the town get water at about 65 feet, which rises to a level 8 or 12 feet from the surface.

VILLA GROVE AND VICINITY.

The village of Villa Grove is situated in the northern arm of the valley, which extends up the valley of San Luis Creek and the upper portion of which is known as Homans Park. The village lies about

9 miles above the upper limit of flowing wells and in all probability some distance also beyond the extreme limits of the sand and clay series in which the artesian water of the valley is found. Owing to the proximity of mountain highland on either side of this narrow tongue of the valley, the sediments consisted largely of sand, gravel, and bowlders without the clay strata necessary to confine the water. The domestic water supply is derived from shallow wells which reach the underflow of Kerber Creek.

The Denver and Rio Grande Railroad in 1891 sunk a well at Villa Grove to a depth of 960 feet in gravel and sand with no clay. The water rose within 100 feet of the top. In 1899 the well was accidentally clogged, and since then it has not been in use.

On the Pitzer ranch, about 6 miles southeast of Villa Grove and 2 miles east of Chamberlain Hot Springs, in the NE. $\frac{1}{4}$ SE. $\frac{1}{4}$ sec. 8, T. 45 N., R. 10 E., a well between 300 and 400 feet deep struck water, which rose within 12 feet of the surface. This well probably strikes the artesian water of the valley, as flowing wells are obtained 3 miles to the south.

CRESTONE AND VICINITY.

The water supply of Crestone is derived from shallow wells, in the gravel of the alluvial slope. These wells reach the underflow of Crestone Creek, which meanders through the village, and they furnish an abundance of water, which, from the situation of the town just at the base of the mountains, is pure and cold. The danger of contamination is wholly local.

On the Baca grant, a mile and a quarter southwest of the village, in the fork of North and South Crestone creeks, a bore went 410 feet in bowlders, with no water. A half mile farther west, at the ranch house, in a well 496 feet deep, the water rose to a level 6 feet below the surface. On Dead Man Creek a bore 1,100 feet deep was all in sand with no water. A mile and a half east of Antelope Springs a 1,000-foot bore yielded no water. These wells on the grant are in the alluvial slope of the Sangre de Cristo Range; and as the clay members of the valley formation do not reach that far there is no confining layer to retain the water under the pressure necessary to yield a flow.

BALDY STATION AND VICINITY.

At the Willie Hansen ranch, 2 miles northwest of Baldy station, on the Denver and Rio Grande Railroad, a number of wells have been bored just about at the margin of the flowing-well area. One in the NE. $\frac{1}{4}$ sec. 17, T. 37 N., R. 12 E., is 500 feet deep, reported all in sand. The water rises within 3 feet of the surface. A half mile due east is another in which the water rises within 10 feet of the top. Two miles due north of Baldy station, near the middle of the north side of

sec. 10, T. 37 N., R. 12 E., a well is reported 300 feet deep, all in sand, in which the water lacks 8 feet of rising to the surface. Near the middle of the west side of sec. 36, T. 38 N., R. 12 E., a well 300 feet deep in sand and gravel is reported to have struck no water whatever. Another well in the NE. ¼ sec. 24, in the same township, well up on the alluvial slope of the Sierra Blanca, struck no water. Though it is evident that the clay beds of the water-bearing series are replaced at about this point by sand and gravel, it is not likely that they terminate so abruptly. It is probable that small clay beds have been overlooked in the wells near the edge of the flowing-well area.

FORT GARLAND AND VICINITY.

The surface wells which furnish the domestic water supply of Fort Garland strike the underflow of Ute Creek. The principal danger of pollution lies in the pastures along the valley of the creek above the town.

On the south bank of Trinchera Creek, in the SW. ¼ sec. 31, T. 30 S., R. 72 W., 4 miles southwest of Fort Garland, a well on W. H. Myers's ranch, 108 feet deep, struck water which rose within 18 inches of the surface. At Frank Beckwith's, in the southwest corner of the SE. ¼ sec. 26, T. 30 S., R. 73 W., a well in Trinchera Valley gave this section:

Section of Beckwith well.

	Thickness.	Depth.
Recent:	*Feet.*	*Feet.*
Soil	4	4
Small bowlders	31	35
Alamosa formation: Clay and sand	118	153

The water rises within 6 feet of the top of the well.

SPRINGS.

The valley affords numerous springs, both large and small. These, with a few exceptions, emerge near the junction of the foothills and the valley bottom. They have mostly the normal temperatures of the shallow artesian waters of the valley, but two springs in the north end of the valley and one near the south end have rather warm temperatures.

McIntire Springs.—The largest group of springs in the valley is that formerly known as Los Ojos, or commonly as McIntire's Springs, on the south side of Conejos River in the northeast corner of sec. 13, T. 35 N., R. 10 E. These springs rise in the bottom just at the foot of one of the San Luis Hills, and some of the springs appear to come up through crevices in the lava. The group is limited to an area not more than 300 feet in diameter, and they all merge into one stream.

The flow from these springs, which is practically constant and does not vary with rainfall, has been measured many times and is found to be about 21 second-feet. The temperature of the stream comprising the united flow of the springs is 60°. Some of the smaller springs have a temperature of 54°, but most of the individual springs are either just over or just under 60°. As these springs rise against or even through comparatively recent lava rocks, their temperature is not a reliable clue to the depth from which they come. A view of these springs looking toward the west, up the valley of Conejos River, is shown in Plate XIII, *B*. An analysis of the water is given in the table on page 112.

The flow of these springs was filed upon at an early date by the inhabitants of the Mexican village of Los Sauces for irrigation purposes, for which its temperature makes it peculiarly valuable in the early season.

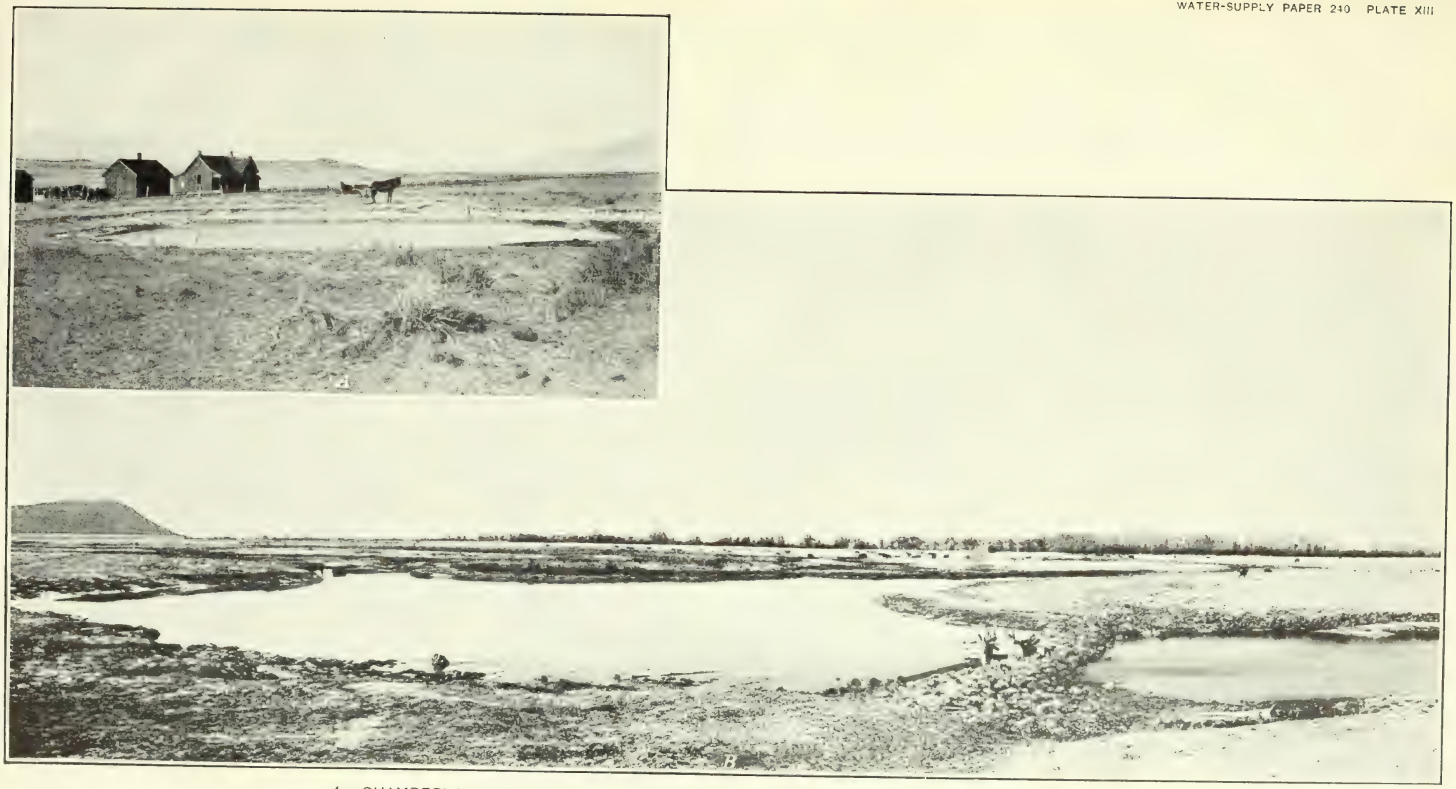
Dexter Spring.—Dexter Spring is on the Austin ranch (formerly the Dexter tract), in the NE. ¼ sec. 9, T. 35 N., R. 11 E., 2 miles northeast of McIntire Springs, and like those springs rises along the edge of the lava bench, which extends from the base of Cerro de los Ojitos, the northernmost of the San Luis Hills, west of the Rio Grande. An analysis of water from this spring is given in the table of analyses, page 112. The temperature is reported to be 71°.

Other springs along Conejos River.—Other smaller springs emerge near the base of the San Luis Hills along Conejos River from a point near its mouth up to the vicinity of Manassa, as was noted on pages 17 and 38, where the supposition was advanced that the water of these springs rises from the water-bearing beds of the Alamosa formation, where they abut against the lava of the Santa Fe formation of the San Luis Hills.

Spring Creek.—Spring Creek has its head in sec. 12, T. 37 N., R. 7 E., half a mile west of the Gunbarrel road and just under the rise of the steeper alluvial slope. Water rises over an area 15 by 40 feet, flowing more than a cubic foot a second. It is augmented by seepage until at the point where it crosses the Gunbarrel road it has a volume of several second-feet. The flow is affected by melting snows in the mountains. It has a temperature of 57°.

Russell Springs.—Russell Springs are situated in the NE. ¼ sec. 24, T. 43 N., R. 7 E. These springs rise in a grassy area 40 acres or so in extent, underlain by a peaty black mud. In this area about twenty-five springs display temperatures ranging from 44° to 56°. The temperature where the water crosses the Gunbarrel road is about 52°. The water has no taste. The water from these springs drains eastward 2 miles into Russell Lakes.

Hunt Springs.—Hunt Springs are in the NE. ¼ sec. 3, T. 44 N., R. 8 E., at the foot of the small lava hill 4 miles east of Saguache.



A. CHAMBERLAIN HOT SPRINGS, LOOKING TOWARD PONCHA PASS. *B*. McINTIRE SPRINGS.

The group comprises about a dozen springs which range in temperature from 43° to 52°. They emerge over an area about 1 acre in extent and nearly on a level with the valley bottom to the east, in which the overflow from the springs forms large marshy ponds, as shown in Plate XII, *B*. The water has no taste and forms no deposit.

Antelope Springs.—Antelope Springs are situated near the middle of the south side of the Luis María Baca Spanish grant. They were not visited by the writer.

Medano Springs.—There are two springs on the Medano ranch. The Big Spring is in the NW. ¼ sec. 2, T. 40 N., R. 12 E. This spring emerges in a circular bed of quicksand 100 feet in diameter, lying at the head of a gully 15 feet deep, which reaches back into the edge of the great dune area. The stream where it first emerges is not large, but it is much increased below by seepage. The temperature of the stream 100 feet below the spring is 51°. The Little Spring lies 2 miles southeast of the Big Spring, in the SW. ¼ sec. 12 of the same township, and is similar to it except in size. These springs, heading in the edge of the great dune area, are popularly and no doubt correctly believed to be the reappearing waters of Mosca and Medano creeks, which disappear beneath the sand several miles to the east.

Washington Springs.—Washington Springs are just north of the Denver and Rio Grande Railroad, in the northeast corner of sec. 14, T. 37 N., R. 11 E. They emerge from the base and even from the top of a small sand dune on the edge of the terrace which is the northern continuation of Hansen Bluff. Those at the base of the mound on the north side flow about 10 gallons a minute. Another forms a pool at the very top of the mound. The temperature of the water is 52°. The dune is covered with grass and is quite the highest point in the vicinity. Presumably the vegetation growing around this spring caught and held the drifting sand, gradually building up the mound, and carrying the spring up with it. On the lower ground, south of the railroad, in the northwest quarter of the same section, a mound 50 yards in diameter has been similarly built up to a height of 20 feet or so. Several small springs emerge from the top and slopes of the mound.

Chamberlain Hot Springs.—The Chamberlain Hot Springs are in the southeast corner of sec. 12, T. 45 N., R. 9 E., and in the SW. ¼ sec. 7, T. 45 N., R. 10 E., near the station on the Denver and Rio Grande Railroad. East of the railroad and just south of the station, in sec. 12, a number of springs bubble up in a large pool about 50 feet in diameter. The temperature is 90° at the edge but is probably higher near the center, where the springs rise. Two other small springs, 25 and 50 yards southeast, have temperatures of 114° and 112°, respectively. The water of the large pool has no taste and shows no tufaceous deposit. Several species of water bugs and an

abundance of the plant *Chara* thrive in the water. The spring was formerly used as a swimming pool, and the water was also piped to a bathing house farther east. The pool, somewhat obscured by rising steam, is shown in Plate XIII, *A*.

The springs in sec. 7 emerge from three small mounds about 50 yards each in diameter and ranging from 20 to 35 feet in height, built up of laminated tufaceous sinter deposited by the springs. No commercial use has been made of these springs for a number of years and no analysis of the water is available.

The springs of the south mound are the most active. The spring by the bath house has a temperature of 127°. A slight but pronounced taste of both soda and iron is evident. There is a yellowish precipitate in the stream flowing away from the spring, and green algæ grow in the spring and along the stream. A pool 20 feet in diameter on the summit of the mound has a temperature of 72°. Other springs near by have temperatures ranging from 128° to 131°.

The east mound has springs on the east and north sides with temperatures ranging from 112° to 124°. The spring on the summit of the mound is extinct.

The north mound is the largest and highest of the three, being about 40 feet high. The springs upon this mound are now extinct, except a group upon a bench on the southeast edge of the mound. These range in temperature from 120° to 130°.

Valley View Hot Springs.—Valley View Hot Springs are in the SW. ¼ sec. 31, T. 46 N., R. 10 E. They emerge from the mountain side a short distance above the upper limit of the alluvial slope. The country rock consists of quartzite. The springs are five in number, three being situated on the north branch of the stream, one on the middle branch, and one, several hundred feet higher up the mountain side, on the south branch. The north spring has a temperature of 72°. The next spring to the south and the largest one of the group, over which there has been built a bath house, has a temperature of 95°. The third spring to the south has a temperature of 87°. The fourth spring, the one on the middle branch, has a temperature of 96° and the one on the south branch a temperature of 99°. The analysis of the largest spring is shown in the table of analyses, page 112. The springs have been improved by the erection of a hotel, a bath house, and several cottages and afford a modest business as a resort.

Hot Creek Springs.—A small stream emptying into La Jara Creek, near Capulin, is known as Agua Caliente, or Hot Creek. The higher temperature of the water in this creek, which renders it so desirable for purposes of irrigation in the early season, is due to hot springs which occur in its upper course.

CHARACTERISTICS OF THE ARTESIAN BASIN.

GROUPING OF WELLS.

A glance at the map will show that by far the greater number of wells in the San Luis basin are along its western slope. Various factors have contributed to this segregation. The principal one, perhaps, has been the presence of greater irrigation systems on that side of the valley and consequent greater population; but another important cause is the fact that the slighter inclination of the strata on that side of the valley has made the matter of obtaining an artesian flow much simpler, involving less chances of failure and less expense.

VARIATIONS IN FLOW.

Seasonal variations.—Near the margin of the area of flowing wells there is a decided periodical variation in pressure or head. Just on the limiting line there are a number of wells that flow during a certain portion of the year and have to be pumped during the remainder of it. The variation in head in these wells is not accurately determined but is about 4 feet. The same variation affects wells within the limits of the flowing-well area, but it there shows itself as a slightly increased or decreased flow and is not so manifest as in wells along the critical line. These wells, with the seasonal intermissions, flow during the summer and fall and do not flow for the rest of the year. As this is the season of irrigation the flow of the wells is popularly said to "come up with the sub." (that is, with the rise of the water table due to subirrigation); and this is probably true, though of course there is no direct connection of the ditch water with the aquifer. The water in the water-carrying stratum is under constant hydrostatic pressure, tending to rise to the surface and pressing upward always against the confining clay bed above. Any increase of weight upon this clay bed is transmitted downward to the aquifer, which, being thus under greater pressure, yields greater flows than before. The water which is put upon the ground in irrigation adds a very definite increment to the pressure upon the aquifer and it is therefore true that the flow rises with the ditch water. Likewise, the rainfall during the showery season adds to the general pressure and helps to increase the head. The seasonal fluctuation due to irrigation is hence closely allied in principle to the tidal fluctuations in artesian wells at the seashore.[a]

Gradual failure of wells.—Several factors contribute to cause the gradual failure of wells. Among these one of the most obvious is the growth of a green alga. This lines the inside of a vertical pipe down for a foot or so, probably as far as light is efficacious, and by

[a] For a summary of the literature relating to tidal fluctuations in artesian wells near the seacoast see Water-Supply Paper U. S. Geol. Survey No. 155, 1906, pp.65–69.

its continued growth often constricts the opening so that the water is forced to a height; and the considerable pressure thus exerted on the well doubtless to an appreciable extent reduces its flow.

Another possible cause of the gradual failure of wells is a reduction of the porosity of the sand bed through which the water comes to the bottom of the well. This has been popularly expressed as a "silting up of the water bed." It seems more reasonable to suppose that the free silica, in which the analyses show the water to be especially high, is by the reduction of pressure at the bottom of the well in part precipitated about the grains of sand in the aquifer adjacent to the bottom of the well, which tends to seal the interstices and to reduce the porosity of the bed. For most of their long journey through the beds of granitic and volcanic sand the artesian waters are undoubtedly augmenting their silica content, as shown by the fact that the silicic acid in water from the Rio Grande at Del Norte is 24 parts per million, whereas that of various wells in the San Luis Valley ranges from 38 to 106 parts per million. But this fact is not in any way inconsistent with the theory that some precipitation of silica may take place as the waters pass from the sands and gravels of the aquifer to the opening at the bottom of the well tube. Decisive proof of this deposition of silica would be had if secondarily enlarged grains of sand should be brought up in cleaning out some old well that had slowly failed. The writer, though repeatedly trying, has as yet failed to obtain such material with which to test the theory.

But presumably the greater number of cases of gradual failure of wells are due to the increase in number beyond the capacity of the aquifer to furnish the full flow for each. The minimum distance from one another at which wells may be put down without affecting the common flow is difficult to determine and depends on the size of the bore, the capacity of the aquifer, and the artesian pressure. It has been shown that the wells in the town of Monte Vista so seriously affect one another that they have ordinarily a uniform flow. The distance there between the wells is from 50 to 200 feet. A mile northwest of La Jara, on William Lambert's place, of two wells 150 feet apart the newer well seriously affected the flow of the old well. It is noticed in all the towns of the valley that the flows now obtained are not so strong as the flows formerly obtained at the same depth, though the adjacent wells may not seem to be affected by the sinking of a new well. The normal flow of wells in towns is often so concealed by the piping or restricted by partial use only that it might be seriously impaired without the fact becoming apparent. Such a failure, of course, may be due in part to other causes, but it is undoubtedly due mainly to the increase of wells. It seems certain that the large wells may be placed as close as 440 yards, and reason-

ably sure that they may be as close as 220 yards, without affecting one another. Smaller wells can of course be placed still closer without mutual injury. If it is desired to have two or more large wells close together, in order that the combined flow may be used for irrigation or stored in a reservoir, they may be so placed if they are bored to different flows and all but the lower flow is cased off from the deeper well. In this way there will be no interference. Instead of sinking two separate wells of different depths, the same effect may be gained by reducing the bore of a large well and continuing it to lower flows, the water from the deeper flows coming up through the smaller inside casing. However, separate wells will in general be preferable, owing to the difficulty of cleaning and repairing multiple wells.

By far the greater number of wells, as will be seen later, are cased only to the first solid clay, a depth varying ordinarily from 10 to 40 or 50 feet. The bore is continued through the various water-bearing beds until a suitable flow is reached. As long as this deeper flow of higher pressure continues the water from the upper water beds will not come into the bore and there will be no mingling of the different flows; but if the well is plugged or is choked near the top, the lower flows, which are under greater pressure, will spread out in the upper beds that are under less pressure, so that the pressure tends to be equalized in the upper and lower flows, and as a result the pressure and consequently the yield of the lower flows are weakened. This process has taken place to such an extent toward the center of the town of Monte Vista that the yield from the various flows is identical, and likewise the temperature.

Sudden failure of wells.—In almost all cases sudden failure is due to the caving away of the clay walls of the well. In a well that is not cased the caving in of the clay anywhere along the bore may shut off the water from below the caved place. In a well that is cased to the sand bed furnishing the flow ordinarily there is a rather large cavity in the sand at the bottom of the casing, resulting from the sand being carried up and thrown out of the well. Occasionally large pieces of the clay bed above may tumble into this cavity and clog the bottom of the casing. In the vicinity of Hooper, and northward on the Kinney ranch, the practice is to let the 1-inch pipe that serves as a drill rod remain in the well after completion. This rod, projecting downward below the casing and into the cavity at the base of the well, ordinarily prevents the complete closure of the well by any falling chunk of clay.

Irregularities in flows from the same aquifer.—Adjacent wells that strike the same water bed may have very different flows. These irregularities are probably to be explained by the irregularities in thickness or porosity of the water-bearing bed. The rate at which

water passes through sand varies with the size of the sand particles, being greater for the coarser varieties. For this reason the gravel flow obtained in certain parts of the valley is a very free, strong flow. Local variations in the same bed of sand therefore exert a very definite effect upon the quantity of flow.

As the rate of flow through sand of a given size is fixed, the volume of flow from any bed of sand of that size depends on the thickness of the bed. It is not to be presumed that the beds of sand in the valley, though known to be of great extent and persistence, are of the same thickness throughout. Any formation built up more or less in delta form, as are the deposits of the Rio Grande alluvial fan, must of necessity differ in thickness from place to place, and such differences are undoubtedly ample to account for any variations in flow from the same bed.

VARIATION IN TEMPERATURE.

VERTICAL VARIATION.

The vertical range in temperature observed in the wells of the valley is from a minimum of 45° in shallow wells to a maximum of 75° for the Bucher well at Alamosa. The increase of temperature with depth is very regular; estimated from the deep cased wells near Alamosa it is 1° for 28½ feet.

The minimum temperature is found in wells on the low ground near the Rio Grande north of Monte Vista. Southward along the Gunbarrel road and southeastward along the flowing-well limit to the vicinity of La Jara the shallowest wells have temperatures of about 46°. Southeast of La Jara along Conejos River the shallowest wells have temperatures of 50° to 52°. North of Monte Vista along the Gunbarrel road the temperature of the first flow likewise increases and in the vicinity of Center it is about 51° or 52°. Farther north, in the Veteran neighborhood, the temperature is lower again, 46° and 47° in wells reaching the first flows. These temperatures continue to the vicinity of Russell Springs, but from there to Swede Corners, 2½ miles north, there is an increase in temperature of 10° in wells of practically the same depth. The area of excessive temperature about Swede Corners has already been described (p. 75). On the east side of the basin the temperatures are very regular and such as would normally be expected, that is to say, 46° and 47° for the first flow.

It is noticeable that the wells of lowest temperature on the west side of the valley are near the courses of the larger streams and that the higher temperatures are found in the interstream areas. The waters of these streams, derived from melting snow for a large part of the year, are notably cold. Daily observations at Del Norte give the

following mean temperatures of the Rio Grande from July 1, 1905, to November 30, 1906, excluding January, February, and March, during which no gage readings are made:

Monthly mean temperature, in degrees Fahrenheit, of the Rio Grande at Del Norte.

[Richard D. Adams, United States Geological Survey, observer.]

	1905.	1906.
April		37.6
May		44.0
June		47.5
July	57.2	53.5
August	56.6	56.0
September	51.0	50.0
October	40.6	40.5
November	35.4	34.7
December	35.8	
Monthly mean	46.1	45.5
Mean of all observations	45.8	

It will be noted that the mean for the period of the observations corresponds closely to the temperature of the coldest wells, namely, 45°. If the observations covered the remaining portion of the year, the winter months would doubtless lower the mean to a point below that of the coldest wells. Water of this mean temperature entering the artesian system is warmed in its passage through the aquifer and, rising rapidly to the surface through the wells, emerges at practically the temperature of the aquifer in the region of the well; but in acquiring this temperature it has abstracted heat from the aquifer. The general loss of heat by radiation from the surface of the earth is counterbalanced by an equivalent upward flow of heat from the internal supply; but in beds as nearly homogeneous as those of the artesian system this increment of heat will be uniform and evenly supplied over the whole area, and thus those areas from which most heat has been abstracted will still remain below the normal temperature. The different beds of the system tend then to become colder and colder, and the first portions to reach the ultimate limit (the mean temperature of the river water) will be those nearer the intake—that is, along the larger streams. That this limit has been practically reached north of Monte Vista has been pointed out above.

This local excessive cooling of the upper strata of the earth is apparently the explanation of the high temperature gradient of 1° for 28½ feet as compared with 1° for 50 or 60 feet, the average increase as found in deep dry wells, shafts, and mines.

The wells with higher temperatures about Swede Corners and along the lower course of the Conejos, with adjacent areas of lava, in all probability derive their excess of heat from subterranean bodies of uncooled igneous rocks. The hot springs which have been described seem likewise to owe their temperature to such a source.

SEASONAL VARIATIONS.

The impression obtains to some extent that the wells of the valley are warmer in winter than in summer. At first thought this would seem to be a delusion, due to the difference in air temperatures in the different seasons affecting the personal standard of comparison. However, in view of the fact that water from the streams enters the aquifers at all seasons of the year with varying temperatures, and that the draft on the wells, and consequently the rate of transmission of the water through the sand, is much greater in the irrigating season, it seems not impossible that there may be seasonal variations. A series of temperature readings was taken of a well in the vicinity of Monte Vista and of two near La Jara.

Variation in temperature of artesian wells.

Date (1906).	1.	2.	3.
July 16	47.2	48.8	.....
August 1	47.5	48.7	.....
August 16	47.4	48.7	45.6
September 1	47.4	48.8	45.8
September 16	47.3	48.8	45.7
October 1	47.2	48.9	45.7
October 16	47.3	48.6	45.8
November 1	47.3	48.6	45.8
November 17	47.2	48.4	.....
December 1	47.2	48.3	.....
December 16	47.2	48.2	45.8

1. La Jara, Eskridge well; SE. ¼ sec. 15, T. 35 N., R. 35 E.; L. A. Norland, observer.
2. La Jara, Mill well; L. A. Norland, observer.
3. Monte Vista, SW. ¼ sec. 19, T. 39 N., R. 8 E.; G. M. Whitead, observer.

These readings show that such variation as exists is measured in tenths of a degree. Well 1 (excluding the first reading, which is probably in error) shows a definite and regular decrease in temperature in the winter. This is a 6-inch well with a small flow. The column of water therefore moves rather slowly up the casing, and there is opportunity for winter ground temperatures to affect the temperature of the water, which they undoubtedly do. In well 2, until after October 1, there was a large flow, and up to that date the readings are valuable. After that date the flow was so reduced that the slow-moving column of water in the well was affected by the ground temperature. Up to the time mentioned the readings indicate a slight rise in temperature. Readings taken at short intervals during a warm day at each of these wells showed no measurable diurnal variation. Well 3, near the limit of flowing wells and the artesian intake from the Rio Grande, is more favorably situated to show such a variation than either of the other two wells. The readings seem to indicate a rise of two-tenths of a degree. It is regrettable that the observations on this well are not extensive enough to be more decisive.

QUALITY OF THE WATER.

In the table on page 112 there have been brought together all available analyses of the well and spring waters of the San Luis Valley. They were variously expressed as grains per United States gallon, grains per imperial gallon, or parts per hundred thousand, but have been uniformly reduced to parts per million and put in terms of ions.

The following determinations of total salts were furnished by the United States Department of Agriculture:

Total salts determined by electrolysis, in well waters of San Luis Valley.

[Bailey E. Brown, analyst.]

	Parts per million.
Well, northwest corner of the NE. ¼ sec. 5, T. 40 N., R. 9 E.	87
Center, town well	87
Center, hotel well	90
Elliott well, NE. ¼ NE. ¼ sec. 13, T. 40 N., R. 7 E.	90
Monte Vista, Elliott well	89

The accuracy of the conductivity method is proportional to the degree of dissociation of the salts in solution. Since these waters are among the best waters of the valley and are in all respects similar to the waters at La Jara and Monte Vista, which yield by gravimetric methods 152 and 156 parts per million of solid matter, respectively, it follows that the dissociation of solutes in the valley water is far from complete. The discrepancy is probably to be ascribed largely to the notable quantity of free silica in these waters. Though not to be relied upon, therefore, to give a correct notion of the total solids, the determinations nevertheless show the relative salinity of the waters included and demonstrate the uniformity of quality over the area covered by the samples.

The analyses in the table (p. 112) with few exceptions, have been made for commercial purposes, mostly with a view to determining the fitness of the waters for boiler use. In certain of the analyses credited to W. P. Headden, however, the process was carried further and supplementary sanitary determinations were made. The amounts of free ammonia and albuminoid ammonia present in two deep artesian wells and two springs are given in the following table:

Ammonia in San Luis Valley waters.

[Parts per million.]

	Free ammonia.	Albuminoid ammonia.
Bucher well	0.112	0.034
McNieland well	.050	.006
McIntire Springs	.106	.092
Dexter Spring	None.	.082

Analyses of ground water in San Luis Valley, Colorado.

[Parts per million.]

Nearest post-office and source.	Date.	Depth.	Color.	Silica.	Iron and alumina.	Calcium.	Magnesium.	Sodium.	Potassium.	Chlorine.	Sulphate radicle.	Carbonate radicle.	Volatile.	Total solids.	Analyst.
Alamosa:															
Alamosa Milling and Elevator Co. well.	Apr. 19, 1893	680	.....	54	1.3	9.6	9.7	35	.....	5.2	14	72	.....	200	Dearborn Drug and Chemical Co.
Blanca farm well	Feb. 3, 1904	840	.....	60	1.9	5.2	.4	67	.....	6.7	11	84	2.0	240	Do.
Bucher well	.....	+1,000	.....	106	.57	5	.2	42	3.8	Trace.	7.9	31	22	228	W. P. Headden.
Do	.....	+1,000	.....	45	Trace.	7.6	.....	32	.....	.....	.....	53	.....	[a] 179	Unknown.
McNieland well	.....	.....	.....	90	.89	3.6	.56	41	3.1	Trace.	9.7	75	.....	251	W. P. Headden.
Antonito: Denver and Rio Grande Railroad well.	.....	242	.....	40	32	43	.86	20	.....	40	2.0	92	.....	[b] 298	Kennicott Water Softener Co.
Hooper:															
Well in sec. 6, T. 40 N., R. 10 E.	.....	.....	.....	.....	.....	.....	15	162	55	.....	16	73	.....	[c] 745	U. S. Dept. Agriculture.
Garrison Mill and Elevator Co. well.	Oct. 14, 1897	740	.....	76	3.6	2.6	2.0	520	.....	7.3	Trace.	679	.....	.....	Dearborn Drug and Chemical Co.
Denver and Rio Grande Railroad well.	.....	614	.....	38	.....	.....	.....	408	.....	2.1	.....	530	134	1,112	Von Schultz & Low.
La Jara: La Jara Milling and Elevator Co. well.	.....	340	.....	41	.99	25	3.1	8	.....	3.4	36	31	2.8	152	Dearborn Drug and Chemical Co.
Moffat: Denver and Rio Grande Railroad well.	.....	1,045	.....	43	.....	.....	.....	47	.....	3.0	.....	58	53	204	Von Schultz & Low.
Monte Vista: Monte Vista Milling Co. well.	Mar., 1897	300	.....	42	1.3	19	2.3	24	.....	7.3	2.4	57	.....	156	Dearborn Drug and Chemical Co.
Mosca:															
Town well	.....	400	.....	64	3.3	3.3	.92	389	8.1	.....	.....	525	91	[d] 1,091	W. P. Headden.
Well on Andersen ranch	Feb. 3, 1904	500	.....	50	7.9	9.2	11	555	.....	6.7	Trace.	759	50	[c] 1,400	Dearborn Drug and Chemical Co.
Well of Mosca Milling and Elevator Co.	.....do.....	600	.....	66	1.9	5.2	4.0	572	.....	6.7	2.9	755	114	[e] 1,418	Do.
Well in sec. 35, T. 39 N., R. 10 E.	.....	500	.....	5.4	4.7	9.6	12	554	.....	10.4	2.0	750	119	1,474	W. P. Headden.
Well in the NW. ¼ NW. ¼ sec. 8, T. 38 N., R. 11 E.	Feb. 3, 1904	800	.....	48	1.3	9.6	2.7	130	.....	51	12	138	42	[e] 396	Dearborn Drug and Chemical Co.
Orient: Valley View Hot Springs.	.....	.....	.....	18.1	[f] .77	53	14	.....	4.7	1.3	69	142	.....	306	Regis Chauvenet.
Los Sauces:															
McIntire Springs	.....	.....	.....	52	1.2	23	2.8	15	2.6	.....	28	45	14	175	W. P. Headden.
Dexter Spring	.....	.....	.....	72	.74	9.4	1.2	24	.....	2.6	25	30	32	198	Do.

[a] Suspended matter, 40.
[b] Suspended matter, 26.
[c] Bicarbonic acid, 424.
[d] Phosphate radicle (PO_4), 6.3.
[e] Total mineral solids.
[f] Iron.

Except in the Mosca-Hooper district, the waters of the valley are of a very good quality, having a maximum total solids of 240 and a minimum of 152 parts per million, as determined by complete analysis. These amounts are two to three times as great as those for the water of the Rio Grande at Del Norte, which contains 88.5 parts per million of total solids. The additional material in solution in the well waters is taken up by the water in its slow passage through the beds of sand and clay making up the water-bearing series.

W. P. Headden [a] has called attention to the unusually high percentage of silicic acid in the mountain waters of Colorado and of the San Luis Valley in particular. The following statement, showing the percentage of silicic acid in the total solids of several waters, is taken from his article:

Percentage of silicic acid in total solids of San Luis Valley waters.

Alamosa, Bucher well	46.9
Alamosa, Spriesterbach well	27.0
Alamosa, McNieland well	36.0
Del Norte, Rio Grande water	27.15
McIntire Springs	29.64

After confirmatory experimental treatment of powdered feldspar with distilled carbonated water, Headden concludes that the high percentage of silicic acid, combined and free, is normal for mountain waters in a region in which feldspar is an essential constituent of the rocks.

Perhaps the most noticeable constituent of the colorless waters, and to a lesser extent of the tinted waters as well, is sulphur. In the form of sulphates, as shown by the analyses, the greatest amount of sulphur is contained in the mill well at La Jara and in the McIntire Springs. Lesser amounts are shown by wells at Alamosa and Monte Vista and least of all by the tinted waters from the Mosca-Hooper district.

Sulphur is also present in the form of sulphureted hydrogen, which may be faintly or decidedly perceptible in most of the well waters of the valley, from both great and small depths. Upon oxidation, as the water is discharged from the well, the free sulphur is deposited in the stream flowing from the well as a gelatinous white precipitate upon vegetation or other objects, which are sometimes turned quite black. Occasionally the precipitate shows the long, delicate waving filaments of some form of sulphur-secreting bacteria, possibly *Thiothrix*.

In a single artesian well there was noticed a decided chalybeate taste and a reddish flocculent ferruginous precipitate in the stream flowing away from the well. This was in lot 1 of sec. 6, T. 43 N., R. 8 E.

[a] Am. Jour. Sci., 4th ser., vol. 16, 1903, pp. 169–184.

In the Mosca-Hooper district the waters are of a yellowish to dull-brown tint and have, for the valley, high contents of the alkalies and organic matter. These wells often give off gas more or less freely, some of them yielding enough to supply a cooking stove. The gas and the color are probably due to the decomposition of peaty moss which apparently grew in the swampy lake at a low stage. Some of the wells which have the deepest tinted waters do not yield gas. The water in wells yielding gas is always tinted, but usually only slightly so. The gas burns brightly with a yellow flame. It has a benzine-like odor, differing in this respect from natural gas elsewhere, which has an odor of sulphureted hydrogen. The amount of organic matter in the tinted waters, varying from 42 to 134 parts per million, is shown in the table of analyses on page 112.

The artesian water of this area is one of its most valuable assets. Cold, palatable, and free from probability of contamination, it must continue to be one of the chief factors in the salubrity of the valley. The tinted waters of the Mosca-Hooper district have a disagreeable taste to one not accustomed to them. The appearance of the water resembles that of rain that has collected in a hollow stump, and the taste is much what one imagines stump water to have. The slight odor of sulphureted hydrogen and the brownish color, together with the effect of imagination, are sufficient to explain this likeness, however. No case is known of injury from the use of the tinted waters, though it seems not unreasonable to suppose that the long-continued use of waters charged as highly with alkalies as these would entail some bad effect.

The colorless waters, containing a large percentage of silica (SiO_2), when used in boilers form considerable scale, which is uniformly hard and tough; the tinted waters of the Mosca-Hooper district, containing less silica but high percentages of the alkaline carbonates, when so used are entirely free from scale but foam badly and also corrode and pit the boiler tubes. This damage is so great that the Denver and Rio Grande Railroad well at Hooper was abandoned for boiler use.

Though containing two to three times as much matter in solution as the ditch water, the clear artesian water along the west side of the valley is used, and has been for years, without injurious effect for irrigation of all crops. The tinted water, however, has a different effect. Along the margin of the streams flowing away from these wells there is always more or less alkali incrustation, and along one such stream, from a well in the NE. $\frac{1}{4}$ sec. 27, T. 39 N., R. 10 E., a strip 10 to 15 feet wide was entirely bare of vegetation and there was much alkali along the margins. Reports as to the deleterious effects of the use of these waters for irrigation vary widely, as is to be expected in view of the fact that the degree to which the water is

tinted is not a conclusive guide to its alkalinity, inasmuch as it depends largely on peaty infusion. Thus some very dark waters may not show such injurious effects as a lighter-colored water that has a higher content of matter in solution. It seems to be pretty generally agreed, however, as the result of experience, that the dark water is nowhere as good as the ditch water and that in many places it is positively harmful and should always, if possible, be used in conjunction with ditch water. Its moderate use is likely to cause a "case-hardening" or the formation of a hard crust on the soil surface. In any event, even if one application is not injurious its continued use in subirrigation will surely impregnate the soil with alkali.

USES OF THE WATER.

The principal use of the artesian water is for household purposes, and most of the houses, even on many of the remote ranches, have running water piped into the kitchen and bathroom. Some wells, particularly in Monte Vista, which have not sufficient head to force water into the houses, yet flow freely at the ground level, are used to operate hydraulic rams, which throw a smaller stream to the desired height.

The artesian water is also especially desirable for stock purposes because of its moderate and constant temperature, which is high enough so that the wells remain open in winter; because of its continuity of supply without pumping or other care; and because of its freedom from contamination. Wells are bored here and there over the stock ranges in the valley by private persons or by neighborhood associations.

The waste flow from the household wells is either run into irrigating ditches or is used for the irrigation of gardens and truck patches. In the towns lawns, gardens, and shade trees are irrigated from the overflow of the wells. The surplus not so used runs into the gutters and is ordinarily collected into a ditch outside the town and used for field irrigation.

In certain sections of the valley the artesian water is an essential factor in irrigation. These regions can be recognized on the map by the close grouping of the wells and by their alignment in rows, ordinarily on the west side of the tracts of land, for this practice is largely confined to the west side of the valley, where the west side of any tract is the higher. Areas where many wells have been sunk for this purpose are (1) the region between Henry station and Bowen schoolhouse; (2) along Rock Creek; (3) in the neighborhood of Veteran schoolhouse; and (4) in the Warner neighborhood. In the first of these localities the wells were sunk for the purpose of irrigating grain, but in the last three chiefly for the purpose of irrigating native hay. Native meadows, since they are not cultivated from year to year,

have many little irregularities and hummocks which can not be irrigated from ditches. It is customary to irrigate such places, if of sufficient area, by a well sunk on the highest point.

In the Veteran and Warner neighborhoods the wells are used to irrigate both grain and hay, and their development was largely the result of the failure of ditch water. For the same reason many wells have been sunk toward the center of the valley in the Hooper and Mosca districts, where the supply of ditch water has been very inadequate in recent years. A recent development of the use of wells for irrigation is the construction of about fifty 6-inch wells in the vicinity of Henry station and westward as far as the Fountain neighborhood. These have in general been very successful.

The average well, if allowed to flow continuously, undisturbed, will wet an area of not more than one-half acre around the mouth of the well. The greater number of wells are used simply to supplement the flow in the ditches. The supply of ditch water early in the season is always sufficient to raise the "sub." Then, later in the season, when the ditch water fails, the ground being already wet, the steady flow of the artesian wells is of great value. Where wells are not to be used in connection with the ditch water a reservoir is a necessity, unless they are very large. In many parts of the valley, owing to the loose texture of the soil, reservoirs will absorb the entire flow of a well for a year before holding water. It is suggested that it would be a good plan to construct reservoirs in the fall and turn in the muddy flood water from the ditch until the bottom of the reservoir is thoroughly wetted and silted up.

It is hard to make a just estimate of the extent of the use of artesian water in irrigation, first, because of the fact, before stated, that the water is in many places turned into the ditches to supplement the ditch flow, and, second, because there is a tendency in the valley to underrate the extent of such use, lest an optimistic estimate should unfavorably affect desired legislation for storage reservoirs in the mountains. It is realized locally that further agricultural expansion depends on the construction of reservoirs to conserve the flood waters, and there is a concerted movement in that direction.

WELLS.

WELL DRILLING.

With a few exceptions the wells of the valley have been sunk by the hydraulic jet process. The exceptions are those which have been drilled through lava, mostly nonflowing wells. The deepest well in the valley, the No. 1 well of the San Luis Oil Company, 1,283 feet deep, was sunk by the hydraulic process, as were many others that reach 1,000 feet or more in depth. The individual drillers have their favorite forms of bits, and their own methods of "rotating" or

"driving" the casing, but the general method of sinking is the same here as elsewhere.

When the well has been sunk into the desired aquifer and the flow is reached, the pump is kept going for some time, a day or more in deep wells, with the object of stirring up the sand and carrying it up the well bore until a considerable cavity is made at the bottom of the well. Water can be delivered to the well only so fast as it can come through the sand walls of the cavity at the bottom of the well. The larger this cavity, the greater the contributing area of sand wall and the greater the volume of water. A new well naturally excavates for itself such a cavity and "throws sand" for several days, often with a pronounced increase of flow. But in the process large lumps may cave away from the clay above and entirely shut off the flow. It is the better plan, therefore, to pump out the cavity while the drill rig is set up over the well, so as to clear away the obstruction if the well chokes up. It is customary in the valley to case only to the first clay bed, through the superficial soil and gravel. This distance varies from 10 to 50 or rarely to 100 feet. Though inevitable, this practice of partial casing is much to be deplored.

Owing to the high freight rates, the item of casing in an average well costs more than the drilling. As long as a new well can be put down for the cost of casing the first one, most people of moderate means, at least in districts where the clay resists the caving fairly well, will prefer to take chances on the caving of the uncased well, especially where the wells are drilled for irrigation purposes as a last resort after successive failures of the ditch water and when immediate results are needed. Many wells, however, are cased down to the main flow that is used. The flow of such a well is affected only by increase in the number of wells, and can be shut off in winter time with impunity, whereas the uncased well is quite likely to cave within a year or so, particularly if plugged in winter. A large percentage of the wells in the valley have fallen off one-half or more in flow, principally through caving in. If caving takes place as a result of plugging the well, it usually happens when the plug is removed. While the well is open the rapid ascent of the water tends to carry to the surface and clear the well of any caved material as fast as it falls. When the well is plugged, however, the water in the bore and to a certain extent in the different aquifers assumes a uniform pressure. This uniformity of pressure has a tendency to favor the disintegration of the walls of the bore. The material breaking away settles downward through the still water in the bore and packs itself in the bottom. When the well is turned on again the amount of material packed in the bottom may be sufficient to cut off the lower flow. Again, the sudden shock of decrease of pressure when the well is suddenly opened by knocking out the plug has likewise a tendency to jar off pieces of the clay wall.

The cost of boring wells, owing to the similarity of the formations, is nearly uniform for similar sizes over the valley. The price of the completed well varies of course with the diameter and depth of the bore hole and the size and length of the casing. The price of casing also varies materially from time to time. The following statement gives the cost of a few typical wells in Alamosa, and the cost of others has been given in preceding pages.

Cost of typical wells in Alamosa.

Two-inch wells:	
230 feet deep, cased about 50 feet	$55
460 feet deep, cased about 50 feet	101
600 feet deep, cased about 50 feet	135
735 feet deep, cased to the bottom	351
Three-inch wells:	
650 feet deep, cased about 50 feet	145
730 feet deep, cased about 50 feet	161
Town well, 5§ inches in diameter:	
865 feet deep, cased to 852 feet	1,865

APPROXIMATE MEASUREMENT OF FLOWING WELLS.

Tables for determining the discharge of water from completely filled vertical and horizontal pipes were prepared a number of years ago by Prof. J. E. Todd, state geologist of South Dakota, who issued a private bulletin describing simple methods of determining quickly, with fair accuracy and with little trouble, the yield of artesian wells. The following tables and explanations relating to vertical and horizontal pipes are taken from this bulletin, with extensions by the present writer. The explanations and tables relating to the measurement in the partly filled horizontal and inclined pipes are from a paper by Charles S. Slichter.[a]

FLOWS FROM FILLED PIPES.

In determining the flow of water discharged through a pipe of uniform diameter all that is necessary is a foot rule, still air, and care in taking measurements. Two methods are proposed, one for pipes discharging vertically, which is particularly applicable before the well is permanently finished, and one for horizontal discharge, which is the most usual way of finishing a well.

The table on page 121 is adapted to wells of moderate size as well as to large wells. If the well is of a diameter not given in the table its discharge can without much difficulty be obtained from the table by remembering that, other things being equal, the discharge varies as the square of the diameter of the pipe. If, for example, the pipe

[a] In Contributions to the hydrology of the eastern United States, 1904: Water-Supply Paper U. S. Geol. Survey No. 110, 1905, pp. 37–42.

is one-half inch in diameter its discharge will be one-fourth of that of a pipe 1 inch in diameter for a stream of the same height. In a similar manner the discharge of a pipe 8 inches in diameter can be obtained by multiplying the discharge of the 4-inch pipe by 4.

In the first method the inside diameter of the pipe should first be measured, then the distance from the end of the pipe to the highest point of the dome of the water above, in a strictly vertical direction—*a* to *b* in the diagram (fig. 14). Find these distances in Table 1; the corresponding figure gives the number of gallons discharged each minute. Wind would not interfere in this case, if only the measurements are taken vertically.

The method for determining the discharge of horizontal pipes requires a little more care. First measure the diameter of the pipe as before; then from a point (*b*, fig. 14) 6 inches vertically below the

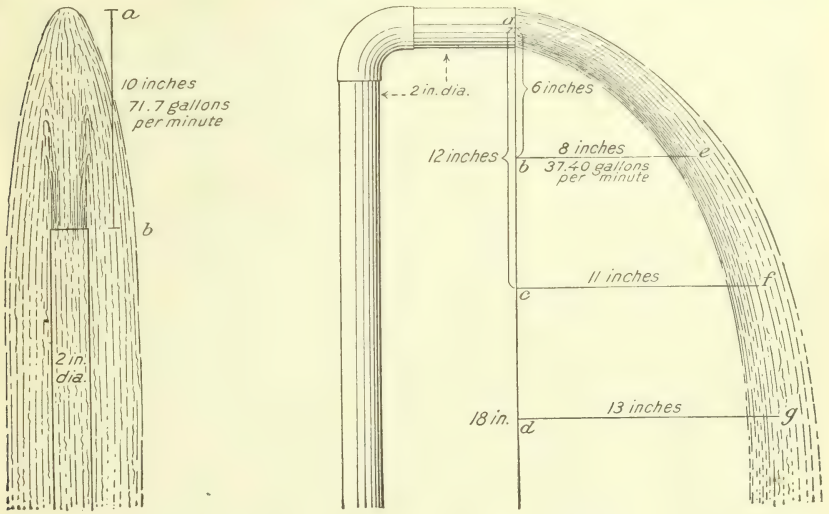


FIGURE 14.—Diagram illustrating flow from vertical and horizontal pipes.

center of the opening of the pipe, or some convenient point corresponding to it on the side of the pipe (*a*), measure strictly horizontally to the center of the stream (*b* to *e*). With these data the flow in gallons per minute can be obtained from Table 2. It will readily be seen that a slight error may make much difference in the result. Care must be taken to measure horizontally and also to the center of the stream. Because of this difficulty it is desirable to check the first determination by a second. For this purpose columns are given in the tables for corresponding measurements from a point 12 inches below the center of the pipe. Of course the same result should be obtained in the two measurements of the same stream. Wind blowing either with or against the water may vitiate results to an indefi-

nite amount; therefore measurements should be taken while the air is still.

Whenever fractions occur in the height or horizontal distance of the stream the number of gallons can be obtained by apportioning the difference between the readings in the table for the nearest whole numbers, according to the size of the fraction. For example, if the distance from the top of the pipe to the top of the stream in the first case is $9\frac{1}{3}$ inches, one-third of the difference between the reading in the table for 9 and 10 inches must be added to the former to give the correct result.

One might suppose that when the flow of a well is measured by both methods the results should agree, but that is not the fact. In the vertical discharge there is less friction, and the flow is larger; so also in the second method differences will be found according to the length of the horizontal pipe used.

As pipes are occasionally set at an angle, it is well to know that the second method can be applied to them if the first measurement is taken strictly vertically from the center of the opening, and the second measurement from that point parallel with the axis of the pipe to the center of the stream, as before. The rates of flow in Table 2 are then applicable.

These tables are based upon a well-known formula of hydraulics. Experiment has shown that a margin of error is involved in the estimates when the height of the jet is less than 2 feet—that in such results there is 5 to 20 per cent or more of excess, which is greater the smaller the pipes and the lower the jets. But these are just the flows that can be most easily measured in a vessel of known size, and this method should always be resorted to when possible. The greater number of the larger wells flow from vertical pipes. Such a pipe may be so close to the ground that the water can not be caught in a receptacle; and not uncommonly it is surrounded by a reservoir, designedly or otherwise, so that it is inconvenient to measure by means of a vessel. For measuring the flow of such wells the tables will be found very convenient.

To convert gallons into cubic feet, divide by 7.5, or, more accurately, by 7.48.

A second-foot equals a flow of 448.8 gallons a minute, or 38.4 Colorado miner's inches. A flow of 100 Colorado miner's inches equals 2.6 second-feet. A flow of 100 Colorado miner's inches equals 1,170 gallons a minute; 1 Colorado miner's inch equals 11.7 gallons a minute.

TABLE 1.—*For determining yield of artesian wells flowing from vertical pipes.*

[Gallons per minute.]

Height of jet.	Yield from pipe with diameter of—					
	1 inch.	2 inches.	3 inches.	4 inches.	5 inches.	6 inches.
In.						
⅛	1.90	6.7	15.2	29.4	47.2	60.8
¼	2.80	10.7	24.0	43.0	69.2	96.0
⅜	3.43	13.6	30.4	54.0	85.5	121.6
½	3.96	15.8	35.6	63.2	98.8	142.1
⅝	4.42	17.8	40.2	71.0	110.8	160.8
¾	4.85	19.5	44.3	78.0	121.6	177.2
⅞	5.24	21.1	48.0	84.1	130.5	192.0
1	5.60	22.4	51.4	89.6	140.0	205.6
1¼	6.29	25.2	57.4	100.5	156.8	229.6
1½	6.90	27.6	62.6	110.2	171.6	250.4
1¾	7.45	29.9	67.5	119.4	186.3	270.0
2	7.99	32.0	71.9	128.0	200.0	287.6
3	9.81	39.2	88.3	146.8	245.0	353.2
4	11.33	45.3	102.0	181.2	283.1	408.0
5	12.68	50.7	113.8	202.8	316.9	455.2
6	13.88	55.5	124.9	222.0	346.9	499.6
7	14.96	59.8	134.9	239.2	373.8	539.6
8	16.00	64.0	144.1	256.0	400.0	576.4
9	17.01	68.0	153.1	272.0	425.0	612.4
10	17.93	71.6	161.3	286.4	447.5	645.2
11	18.80	75.2	169.3	300.8	470.0	677.2
12	19.65	78.6	176.9	314.4	491.3	707.6
13	20.46	81.8	184.1	327.2	511.3	736.4
14	21.22	84.9	190.9	339.6	530.6	763.6
15	21.95	87.8	197.5	351.2	548.8	790.0
16	22.67	90.7	203.9	362.8	566.9	815.6
17	23.37	93.5	210.3	374.0	584.4	841.2
18	24.06	96.2	216.5	384.8	601.3	866.0
19	24.72	98.9	222.5	395.6	618.1	890.0
20	25.37	101.6	228.5	406.4	635.0	914.0
21	26.02	104.2	234.3	416.8	651.3	937.2
22	26.66	106.7	240.0	426.8	666.9	960.0
23	27.28	109.2	245.6	436.8	682.5	482.4
24	27.90	111.6	251.1	446.4	697.5	1,004.4
25	28.49	114.0	256.4	456.0	715.5	1,025.6
26	29.05	116.2	261.4	464.8	726.3	1,045.6
27	29.59	118.2	266.1	472.8	738.8	1,064.4
28	30.08	120.3	270.4	481.2	751.9	1,081.6
29	30.55	121.9	274.1	487.6	761.9	1,096.4
30	30.94	123.4	277.6	493.6	771.3	1,110.4
36	34.1	136.3	306.6	545.2	851.9	1,226.4
48	39.1	156.5	352.1	626.0	978.1	1,408.4
60	43.8	175.2	394.3	700.8	1,095.0	1,577.2
72	48.2	192.9	434.0	771.6	1,205.6	1,736.0
84	51.9	207.6	467.0	830.4	1,297.5	1,868.0
96	55.6	222.2	500.0	888.8	1,388.8	2,000.0
108	58.9	235.9	530.8	943.6	1,474.4	2,123.2
120	62.2	248.7	559.5	984.8	1,554.4	2,238.0
132	65.1	260.4	585.9	1,041.6	1,627.5	2,343.6
144	68.0	272.2	612.5	1,088.8	1,701.3	2,450.0

TABLE 2.—*For determining yield of artesian wells flowing from horizontal pipes.*

[Gallons per minute.]

Horizontal length of jet.	1-inch pipe.		2-inch pipe.		3-inch pipe.	
	6-inch level.	12-inch level.	6-inch level.	12-inch level.	6-inch level.	12-inch level.
In.						
6	7.01	4.95	27.71	19.63	62.35	44.17
7	8.18	5.77	32.33	22.90	72.74	51.53
8	9.35	6.60	36.94	26.18	83.12	58.91
9	10.51	7.42	41.56	29.45	93.51	66.26
10	11.68	8.25	46.18	32.72	103.91	73.62
11	12.85	9.08	50.80	35.99	114.30	80.98
12	14.02	9.91	55.42	39.26	124.70	88.34
13	15.19	10.73	60.03	42.54	135.07	95.72
14	16.36	11.56	64.65	45.81	145.46	103.07
15	17.53	12.38	69.27	49.08	155.86	110.43
16	18.70	13.21	73.89	52.35	166.25	117.79
17	19.87	14.04	78.51	55.62	176.65	125.15
18	21.04	14.86	83.12	58.90	187.02	132.53
19	22.21	15.69	87.74	62.17	197.42	139.88
20	23.37	16.51	92.36	65.44	207.81	147.24
21	24.54	17.34	96.98	68.71	218.21	154.60
22	25.71	18.17	101.60	71.98	228.60	161.96
23	26.88	18.99	106.21	75.26	238.97	169.34
24	28.04	19.82	110.83	78.53	249.37	176.69
25	29.11	20.64	115.45	81.80	259.76	184.05
26	30.38	21.47	120.07	85.07	270.16	191.41
27	31.55	22.29	124.69	88.34	280.55	198.77
28	32.72	23.12	129.30	91.62	290.93	206.15
29	33.89	23.95	133.92	94.89	301.32	213.50
30	35.06	24.77	138.54	98.16	311.72	220.86
31	36.23	25.59	143.16	101.43	322.11	228.22
32	37.40	26.42	147.78	104.70	332.51	235.58
33	38.57	27.25	152.39	107.98	342.88	242.96
34	39.64	28.08	157.01	111.25	353.27	250.31
35	40.45	28.64	161.63	114.52	363.67	257.67
36	41.60	29.46	166.25	117.79	374.06	265.03
Continue by adding for each inch						
	1.15	0.82	4.62	3.27	10.39	7.36

The flow in pipes of diameters not given in the table can easily be obtained in the following manner:

For $\frac{1}{2}$-inch pipe, multiply discharge of 1-inch pipe by..... 0.25
For $\frac{3}{4}$-inch pipe, multiply discharge of 1-inch pipe by..... 0.56
For $1\frac{1}{4}$-inch pipe, multiply discharge of 1-inch pipe by..... 1.56
For $1\frac{1}{2}$-inch pipe, multiply discharge of 1-inch pipe by..... 2.25
For 3-inch pipe, multiply discharge of 2-inch pipe by..... 2.25
For 4-inch pipe, multiply discharge of 2-inch pipe by..... 4.00
For $4\frac{1}{2}$-inch pipe, multiply discharge of 2-inch pipe by..... 5.06
For 5-inch pipe, multiply discharge of 2-inch pipe by..... 6.25
For 6-inch pipe, multiply discharge of 2-inch pipe by..... 9.00
For 8-inch pipe, multiply discharge of 2-inch pipe by..... 16.00

MEASUREMENT OF FLOWS FROM PARTLY FILLED PIPES.

From Table 3 below it should be possible, if the wind is not blowing too hard, to determine the flow from a partly filled pipe with an error probably not exceeding 10 per cent. This error is no greater than the fluctuation of the flow due to the daily variations of the barometric pressure in most wells. The results in extreme cases, such as a

¼-inch stream in a 6-inch pipe are, of course, still less accurate, and actual measurement by collecting the water in a vessel of definite capacity should be resorted to if possible.

TABLE 3.—*For estimating the discharge from partly filled horizontal or sloping pipes.*

Fractional part of diameter of pipe not occupied by water. [Obtained by dividing A D by A B in fig. 1.]	Discharge expressed as percentage of discharge from full pipe, same size.	Fractional part of diameter of pipe not occupied by water. [Obtained by dividing A D by A B in fig. 1.]	Discharge expressed as percentage of discharge from full pipe, same size.
0.05	0.98	0.55	0.44
.10	.95	.60	.37
.15	.91	.65	.31
.20	.86	.70	.25
.25	.80	.75	.20
.30	.75	.80	.14
.35	.69	.85	.092
.40	.63	.90	.054
.45	.55	.95	.015
.50	.50	1.00	.000

To estimate the discharge from a partly filled horizontal or sloping pipe, first estimate the discharge from full pipe of the same size by means of Table 2.

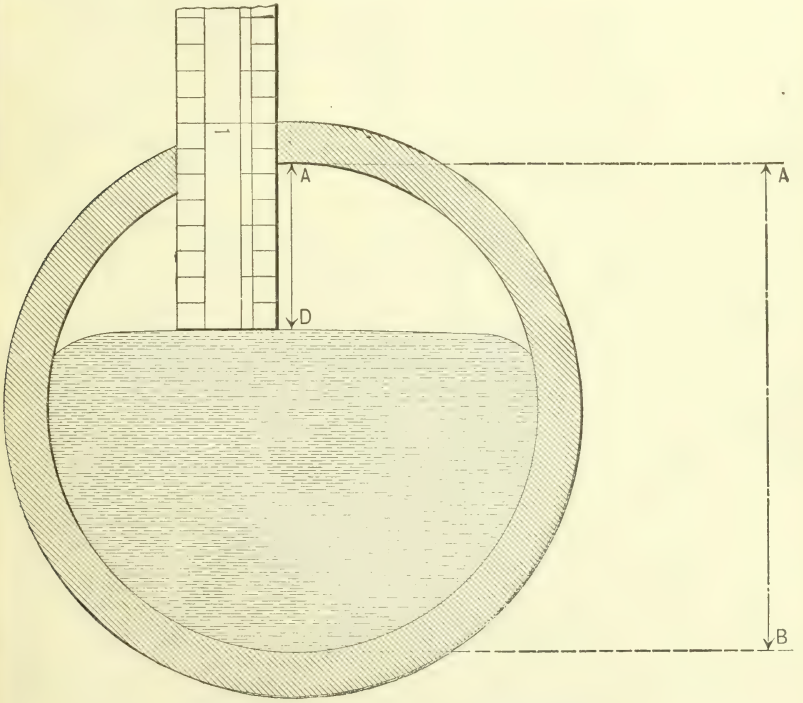


FIGURE 15.—Method of measuring partly filled pipes.

Next measure with a foot rule the dimension A D (fig. 15) of the empty portion of the cross section of the pipe. Divide this by the

inside diameter of the pipe, which will give the fractional part of the diameter that is occupied by the empty part of the pipe. In Table 3 find in the first column the number nearest to the above quotient. Opposite this number will be found the percentage of the discharge of the full pipe that the partly filled pipe is yielding. It is sufficient to measure the distance A D to the nearest eighth of an inch, or at most to the nearest sixteenth of an inch.

Suppose that a 2-inch horizontal pipe has a length of jet of 13 inches at 6-inch level. From Table 2 this would represent a discharge of 60 gallons per minute from the full pipe. Suppose that the distance A D is five-eighths of an inch and A B is 2 inches, or sixteen-eighths of an inch. Dividing 5 by 16 gives 0.31. In the first column of Table 3 we find 0.30, the nearest to 0.31, and opposite 0.30 in the second column of the table appears 0.75. The discharge from the partly filled pipe is therefore $60 \times 0.75 = 45$ gallons per minute.

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TOPOGRAPHIC MAP
OF
SAN LUIS VALLEY, COLORADO

By C E Siebenthal

1906

Miles

Contour intervals

Black contours 200 feet Brown contours 100 and 50 feet

1909

Compiled from Hayden's Atlas of Colorado
with additions by C E Siebenthal

LEGEND

Flowing wells

Non-flowing wells

Areas of flowing wells

Limit of gas fields

Limit of cultivated lands

Mines

SAGUACHE MTS

SAN JUAN

RANGE

LA GARITA HILLS

SANGRE DE CRISTO

Poncha Pass

Hayden Pass

Music Pass

Mosca Pass

HUNTS PK

EL VALLE PK

ELECTRIC PK

KIT CARSON PK

CRESTONE PK

Alder Creek

Alder Creek Hot Springs

Chalybeate Hot Springs

Mineral Creek

Mineral Hot Springs

Saguache

Del Norte

Crestone

Russell Lakes

Willow Creek

Cottonwood Creek

Dunes

LUIS MARIA BACA GRANT

Medano Ranch

Medano Springs

Hot Springs

Head Lake

Sand Dunes

Sand Lake

Mosca

Medano Creek

Saguache Creek

Trinchera Creek

Rio Grande

Rio Grande Reservoir

Rio Grande Canal

Rio Grande Ditch

Rio Grande Extension Canal

Rio Grande Extension Ditch

Rio Grande Reservoir and Irrigation Co's Canal

Rio Grande Reservoir and Irrigation Co's Ditch

Rio Grande Reservoir and Irrigation Co's Extension Canal

Rio Grande Reservoir and Irrigation Co's Extension Ditch

Rio Grande Reservoir and Irrigation Co's Extension Canal

Rio Grande Reservoir and Irrigation Co's Extension Ditch

SIERRA BLANCA

TRINCHERA ESTATE

COSTILLA ESTATE

SAN LUIS VALLEY

SAN LUIS HILLS

SANGRE DE CRISTO MOUNTAINS

SAN PEDRO MESA

Mosca Pass

Medano Springs

Little Spring

Big Spring

Head Lake

Medano Ranch

Zapata Ranch

Mosca

Hooper

Center

Mineta

Mount Vista

Mellmix

Alamosa

Hayes

Washington Springs

Hansen Bldg.

Colfax Ranch

Calhan Ranch

Gra-Back Pk.

Old Baldy

Lanca Pk.

Pinada Pk.

Chiquita Pk.

Trinchera Pk.

Blanca Pk.

Wolf Creek

Sand Dunes

Alamosa River

Rio Grande

Conejos River

Trinchera Creek

Medano Creek

Saguache Creek

Ute Creek

Sangre de Cristo Range

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